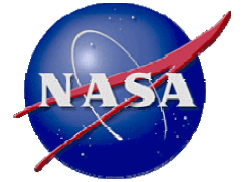


National Aeronautics and Space Administration

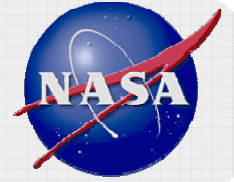


Orbital Debris and Future Environment Remediation

J.-C. Liou, PhD

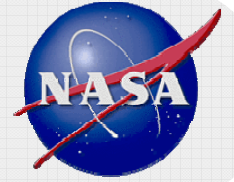
**NASA Orbital Debris Program Office
Johnson Space Center, Houston, Texas**

**Presentations at the Korea Aerospace Research Institute (KARI)
Daejeon, Korea, 21-22 November 2011**



Outline

- **Part 1 (Nov 21st): The Near-Earth Orbital Debris Environment**
 - Overview of the orbital debris populations
 - Optical, radar, and in-situ measurements
 - Orbital debris modeling
- **Part 2 (Nov 22nd): Environment Remediation and Active Debris Removal**
 - Projected growth of the future debris population
 - The need for active debris removal (ADR)
 - A grand challenge for the 21st century
 - The forward path

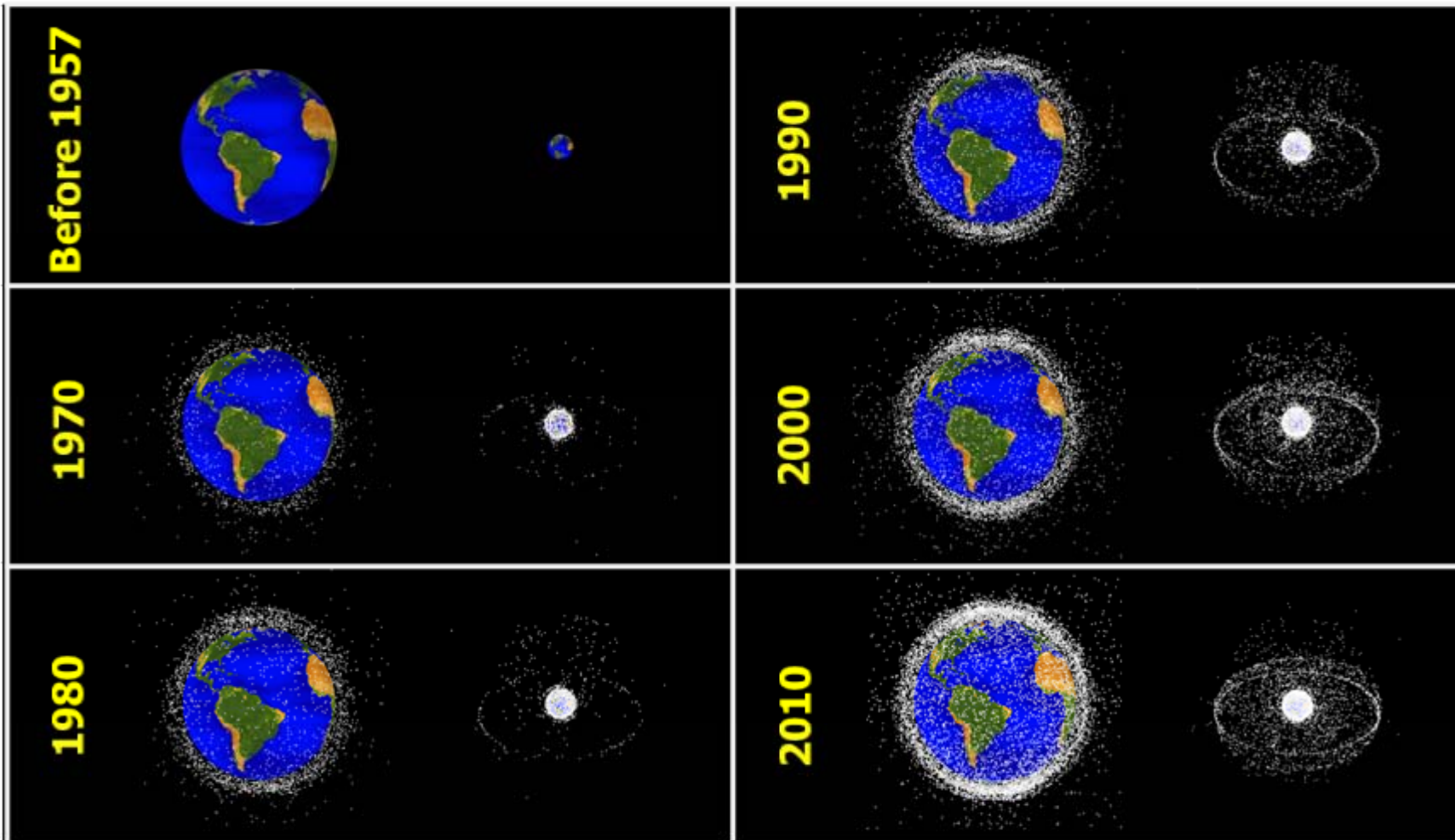
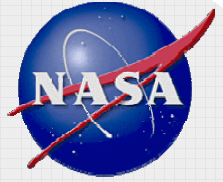


Part 1: The Near-Earth Orbital Debris Environment

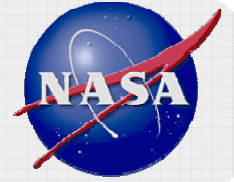


Overview of the Orbital Debris Environment

The Near-Earth Environment (1957-2010)

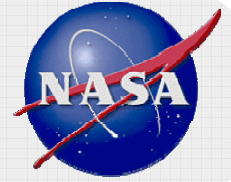


- Only objects in the US Space Surveillance Network (SSN) catalog are shown
- Sizes of the dots are not to scale



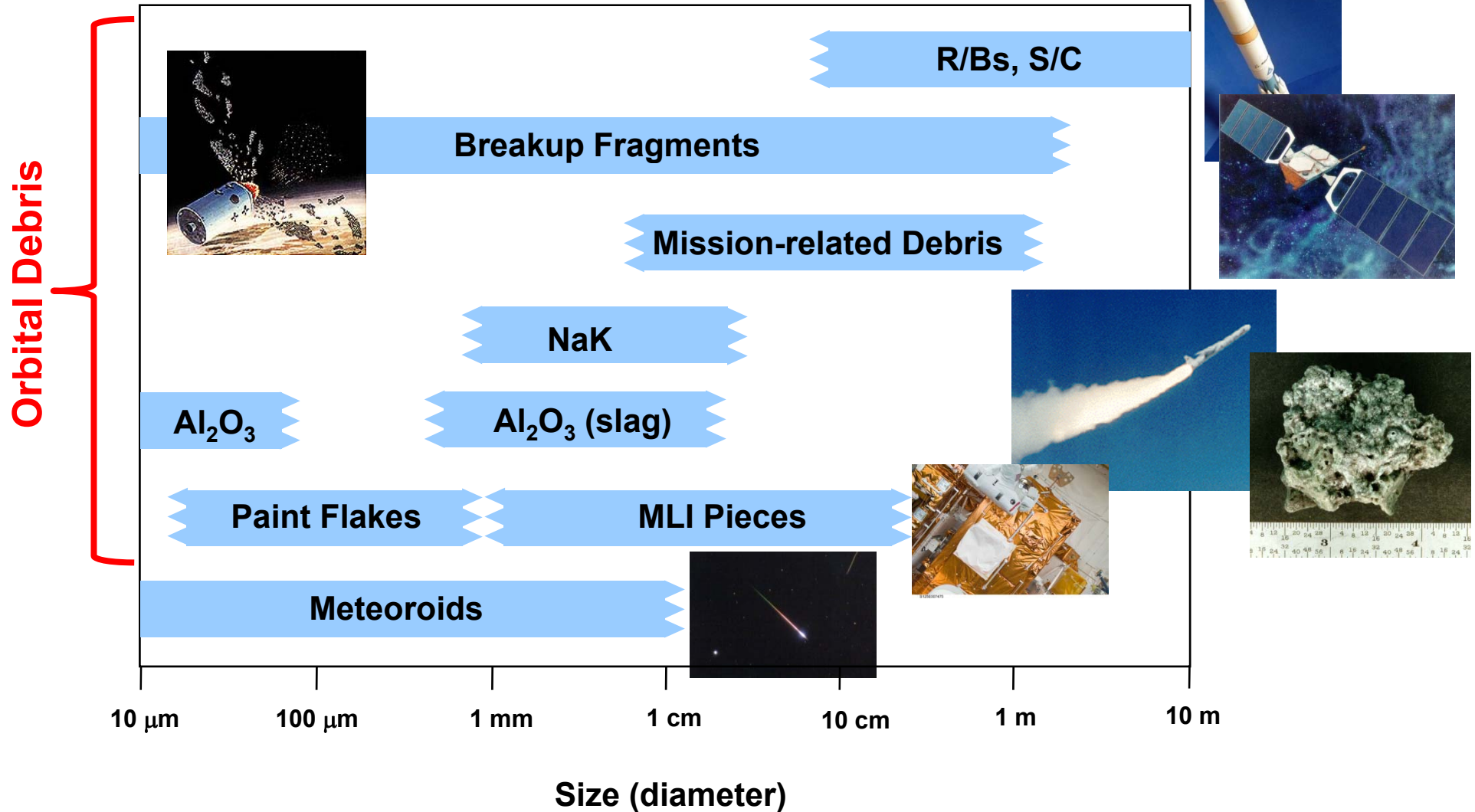
What Is Orbital Debris?

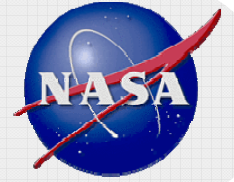
- **Orbital debris is any man-made object in orbit about the Earth that no longer serves a useful purpose**
- **Examples**
 - Intacts: Spent rocket bodies (R/Bs, *i.e.*, upper stages) and retired spacecraft (S/C, *i.e.*, payloads)
 - Breakup fragments (via explosions or collisions)
 - Mission-related debris: objects released during normal mission operations (engine covers, yo-yo despin weights, *etc.*)
 - Solid rocket motor effluents (Al_2O_3 slag and dust particles)
 - NaK droplets (coolant leaked from Russian nuclear reactors)
 - Surface degradation debris (paint flakes, *etc.*)



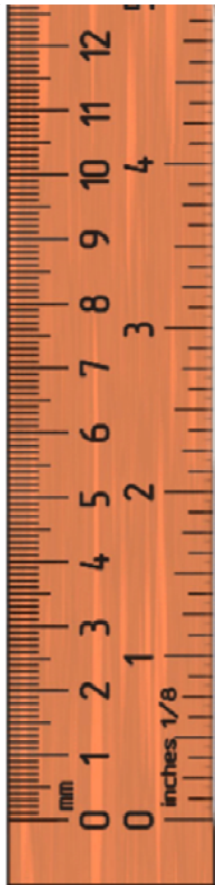
The Orbital Debris Family

Objects in the Near-Earth Environment





How Much Junk Is Currently Up There?



**Softball size or larger (≥ 10 cm): ~22,000
(tracked by the Space Surveillance Network)**

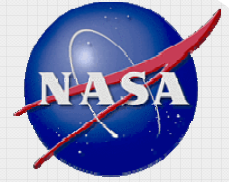


Marble size or larger (≥ 1 cm): ~500,000

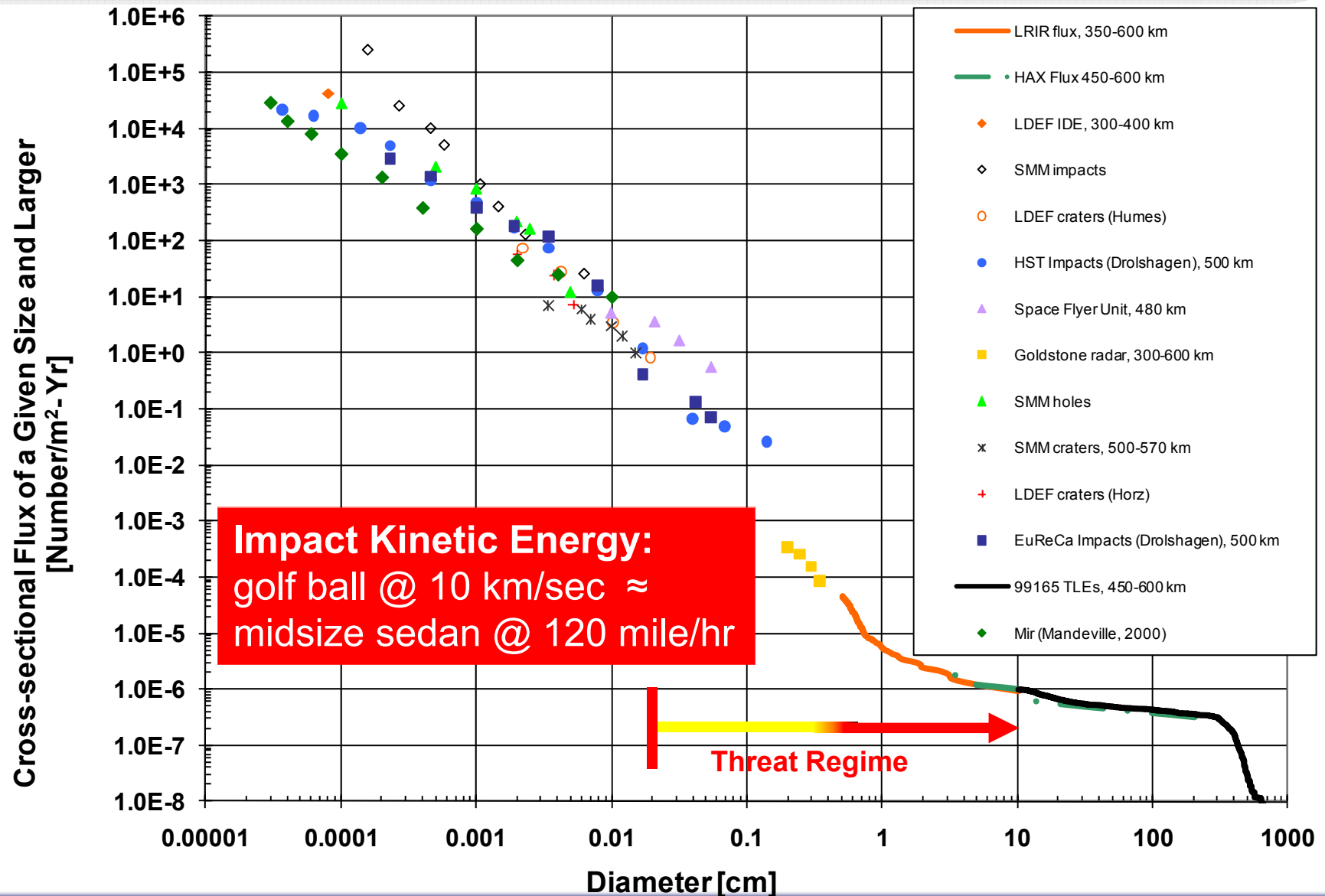


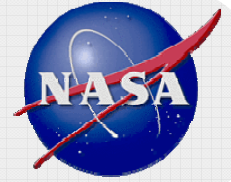
**Dot or larger (≥ 1 mm): ~100,000,000
(a grain of salt)**

- Total mass: ~6300 tons LEO-to-GEO (~2700 tons in LEO)
- Debris as small as 0.2 mm pose a realistic threat to Human Space Flight (EVA suit penetration, Shuttle window replacement)



The Environment





An Example – Shuttle Vulnerabilities

Potential Shuttle Damage

Window Replacement

EVA Suit Penetration

Radiator Penetration



- Shuttle Loss of Crew and Vehicle (LOCV) risks from MMOD impact damage are in the range of **1 in 250** to **1 in 300** per mission
 - The risks vary with altitude, mission duration, and attitude
 - OD to MM is about 2:1 at ISS altitude



0.001

0.01

0.1

1

10

100

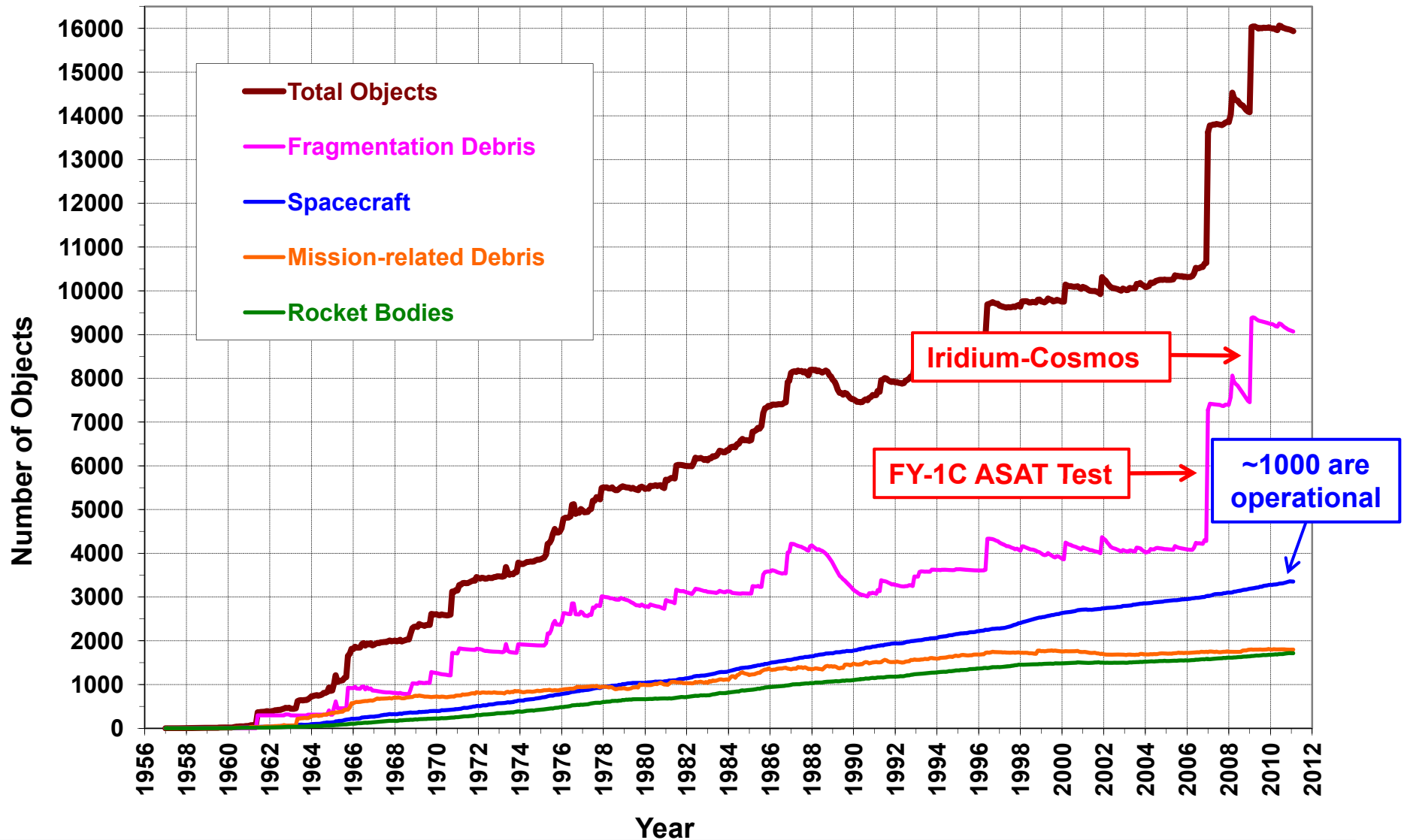
1000

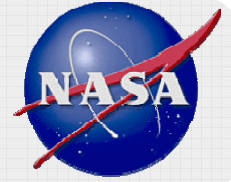
Debris Diameter in Centimeters



Growth of the Historical Catalog Populations

Monthly Number of Objects in Earth Orbit by Object Type (SSN Catalog)





Sources of the Catalog Populations

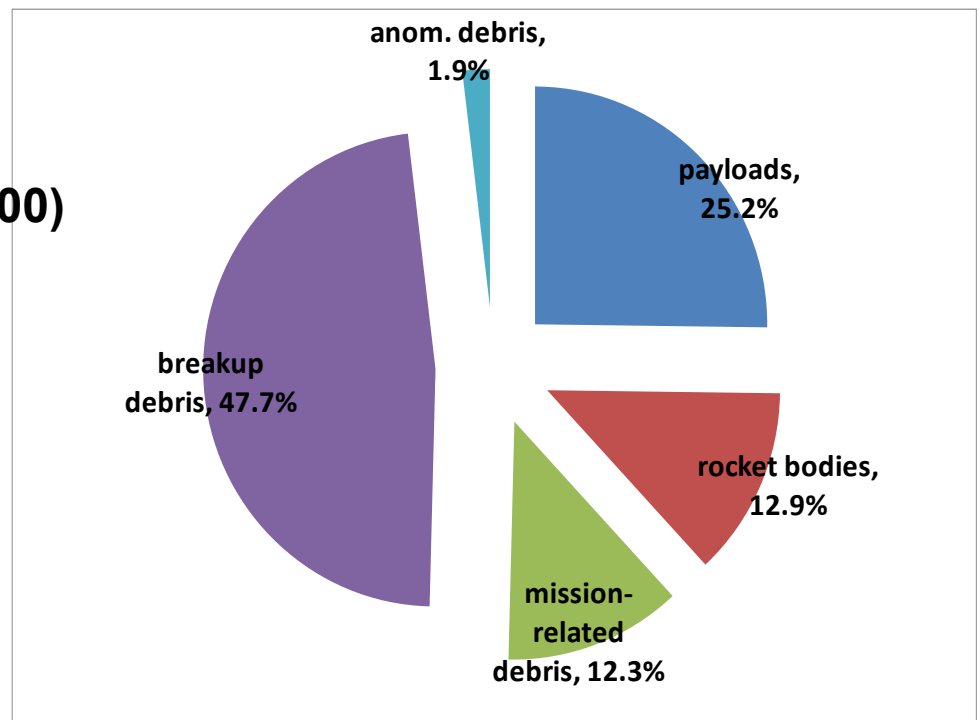
- ~4700 launches conducted worldwide since 1957
- 208 known breakups

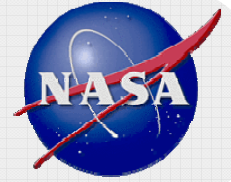
– Major events:

- Titan Transtage (473, 1965)
- Agena D stage (373, 1970)
- Ariane 1 stage (489, 1986)
- Pegasus HAPS (709, 1996)
- Long March 4 stage (316, 2000)
- PSLV (326, 2001)
- **Fengyun 1C** (~3200, 2007)
- Briz-M (>1000^a, 2007)
- Cosmos 2421 (509, 2008)
- **Iridium 33** (>700, 2009)
- **Cosmos 2251** (>1500, 2009)

^ainitial report

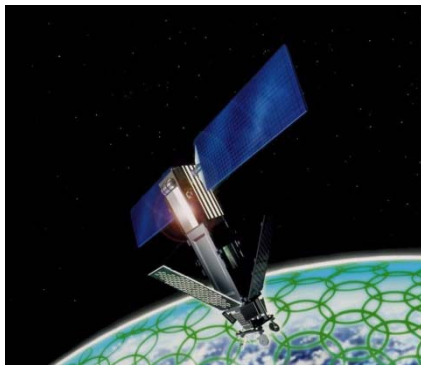
Source Breakdown





Accidental On-Orbit Collisions

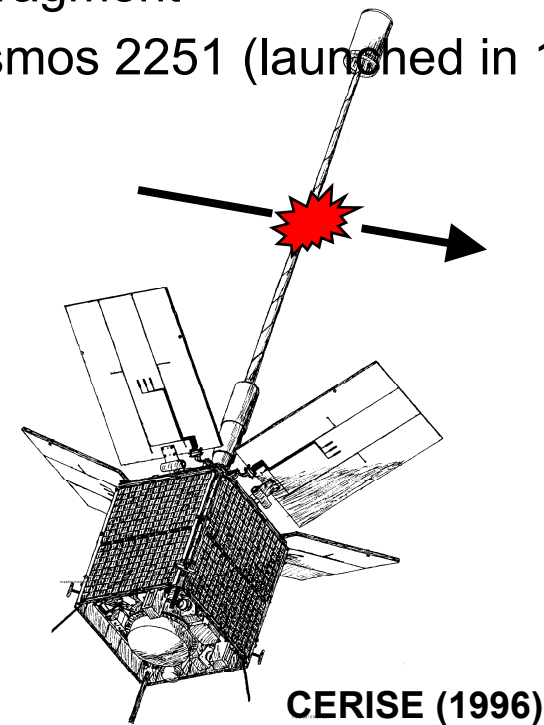
- **Four accidental collisions between cataloged objects have been identified**
 - 1991: Russian Sat (launched in 1988) ↔ Russian fragment
 - 1996: French Sat (launched in 1995) ↔ French fragment
 - 2005: US R/B (launched in 1974) ↔ PRC fragment
 - 2009: Iridium 33 (launched in 1997) ↔ Cosmos 2251 (launched in 1993)



Iridium33
(560 kg)



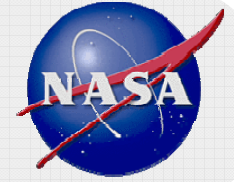
Cosmos 2251
(900 kg)



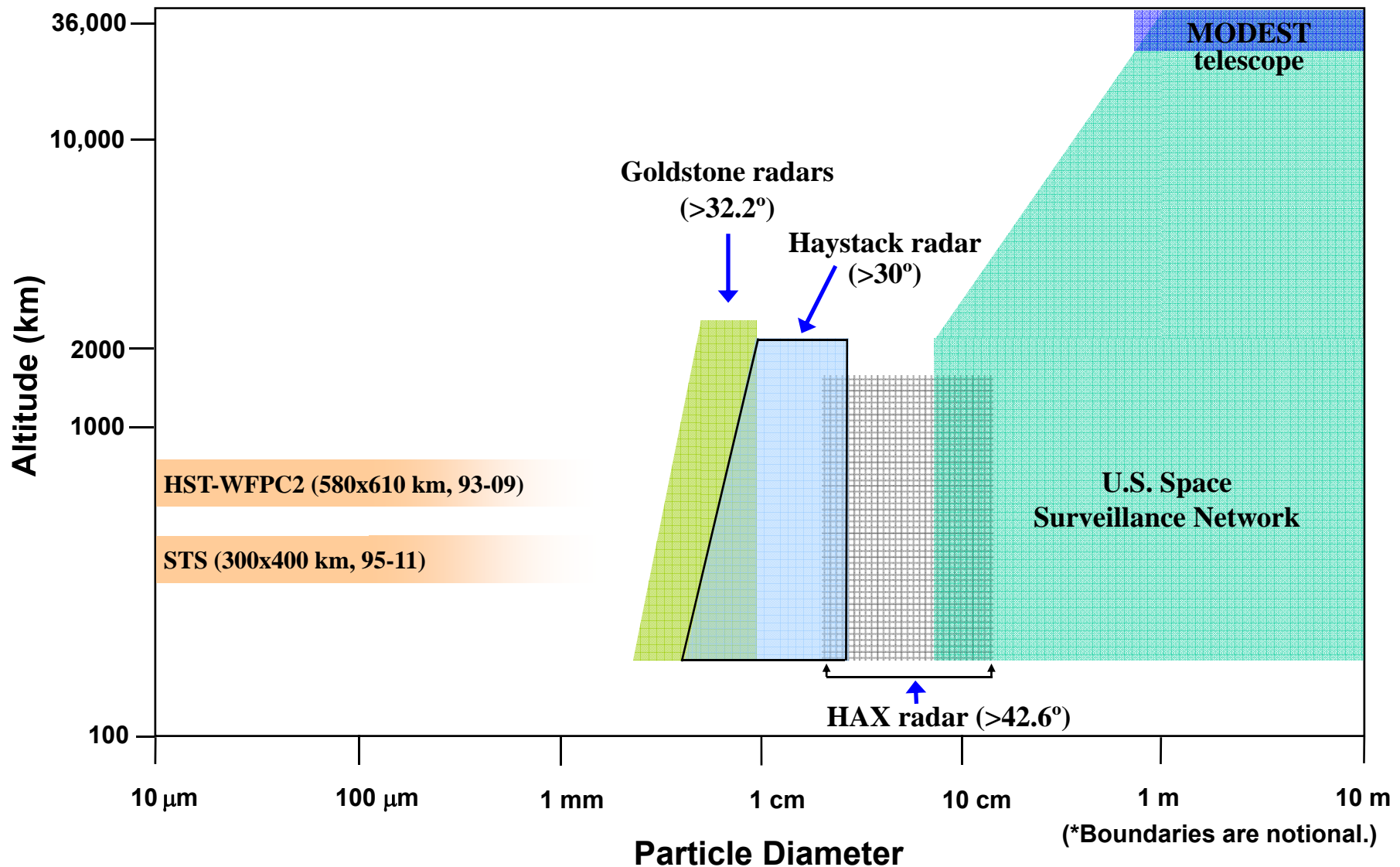
CERISE (1996)

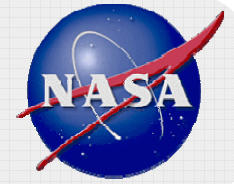


Optical, Radar, and In-Situ Measurements

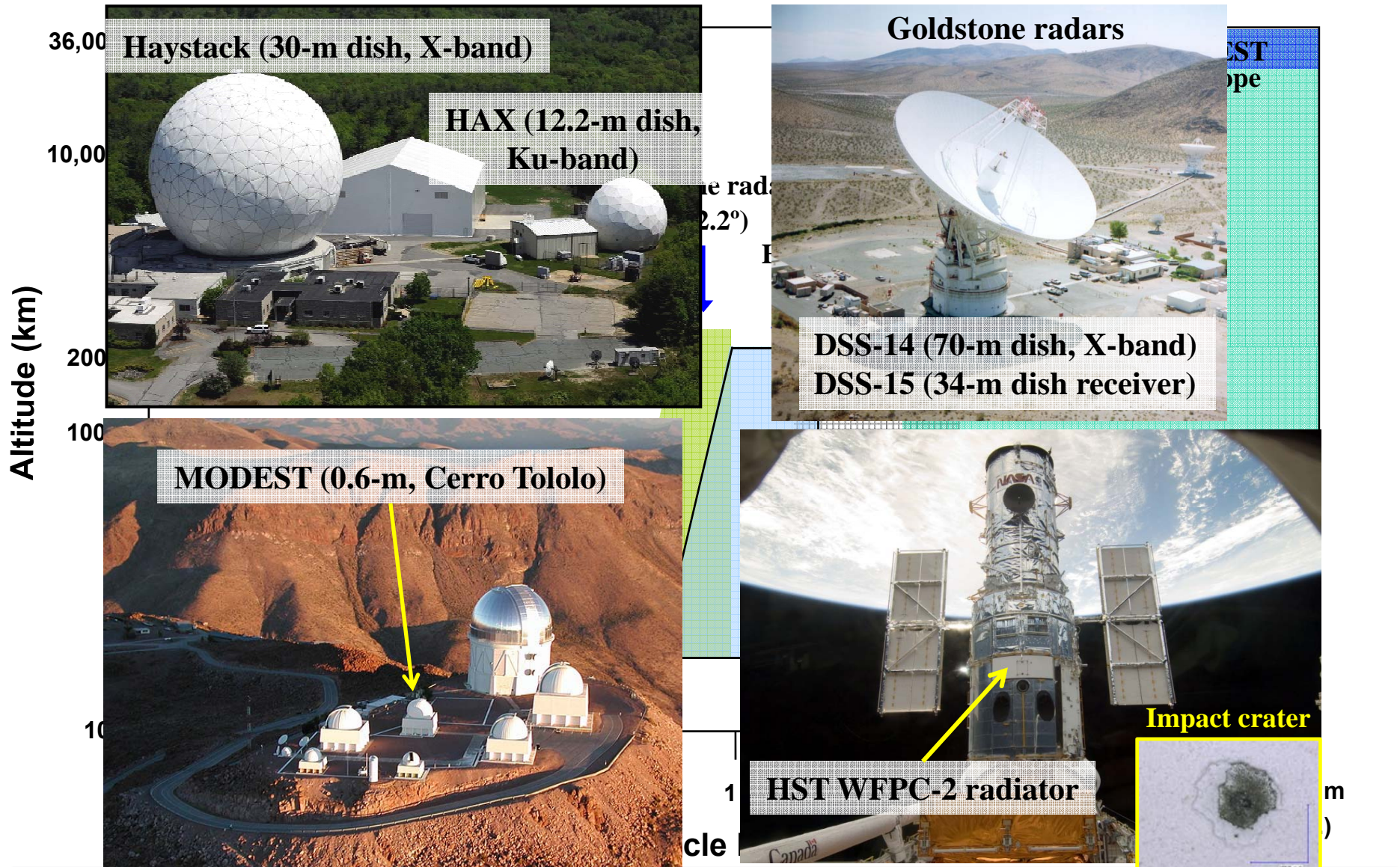


Current NASA Debris Data (1/2)





Current NASA Debris Data (2/2)





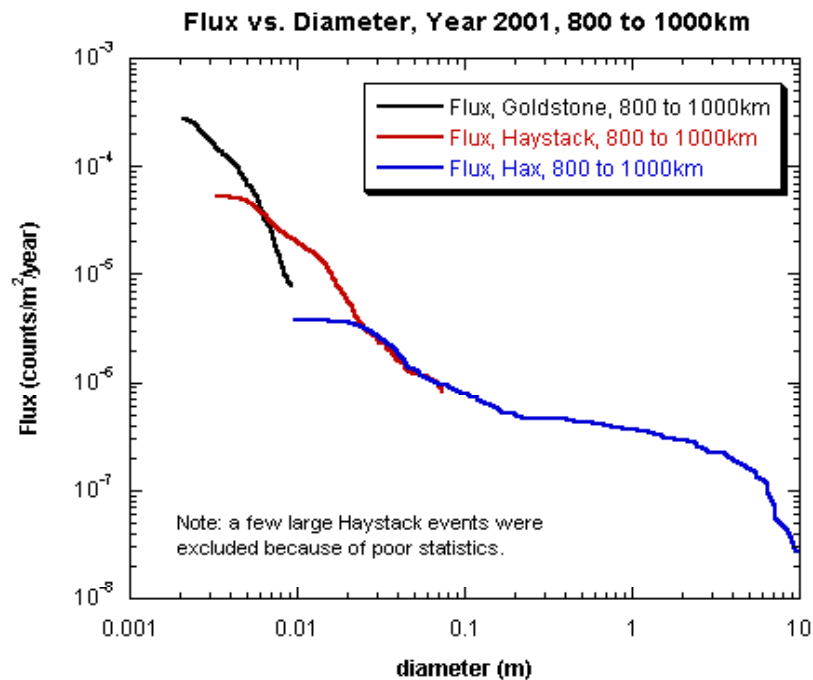
NASA RADAR Observations

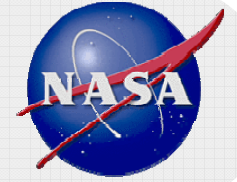
- Signal processing
- Object detection/correlation
- Debris size estimation
- Orbit determination
- Environment definition

Goldstone



Haystack and HAX



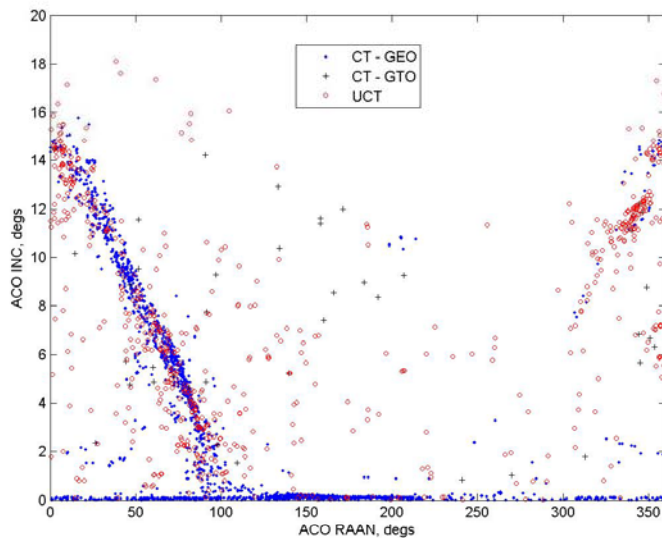


NASA Optical Observations

- Photometric and spectral measurements
- Object detection and correlation
- Optical Measurement Center (OMC)
- Surface material identification
- Orbit determination
- Environment definition



MODEST



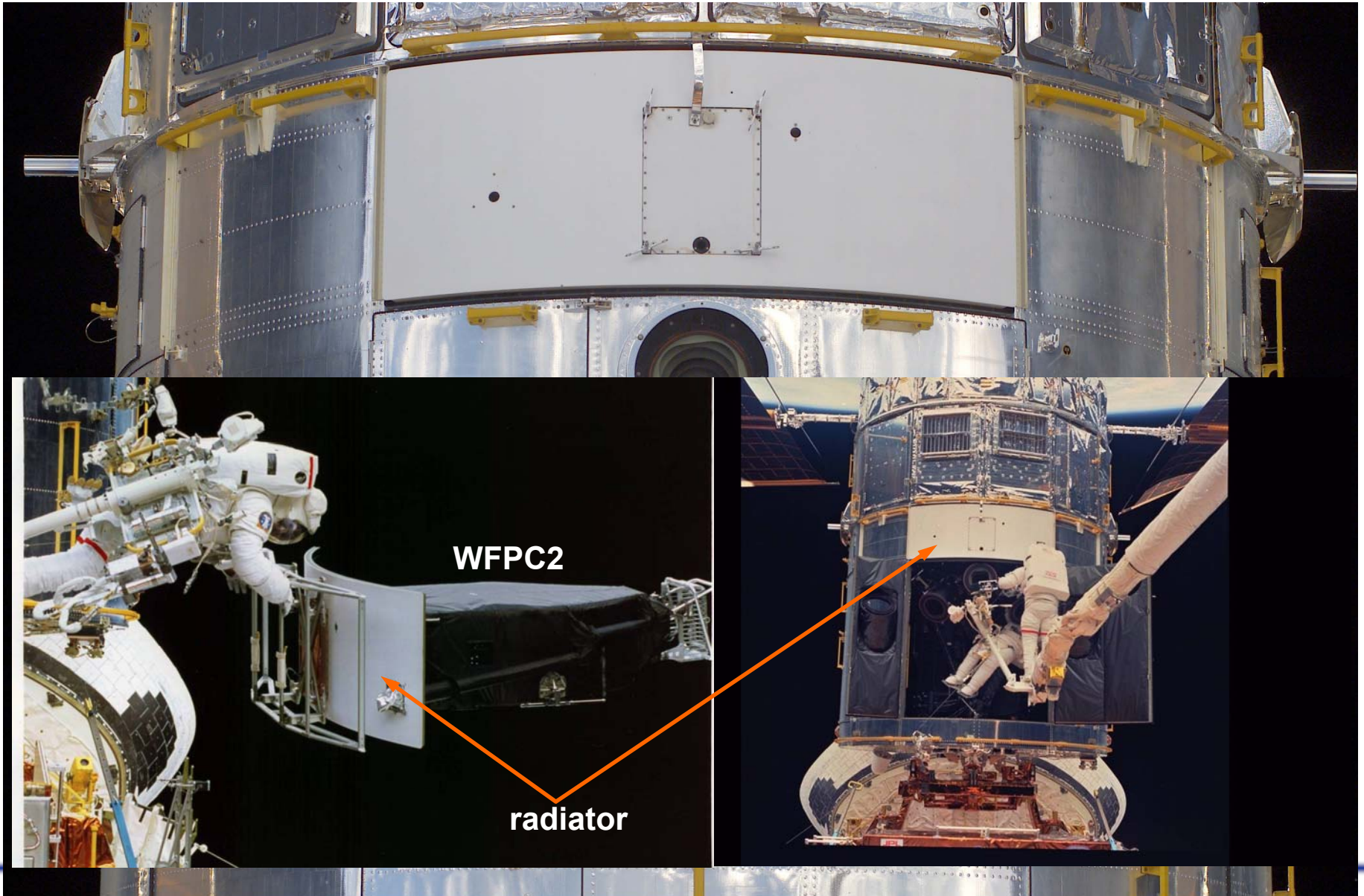
OMC

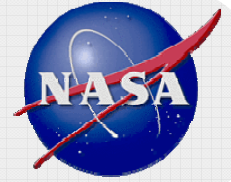
MCAT





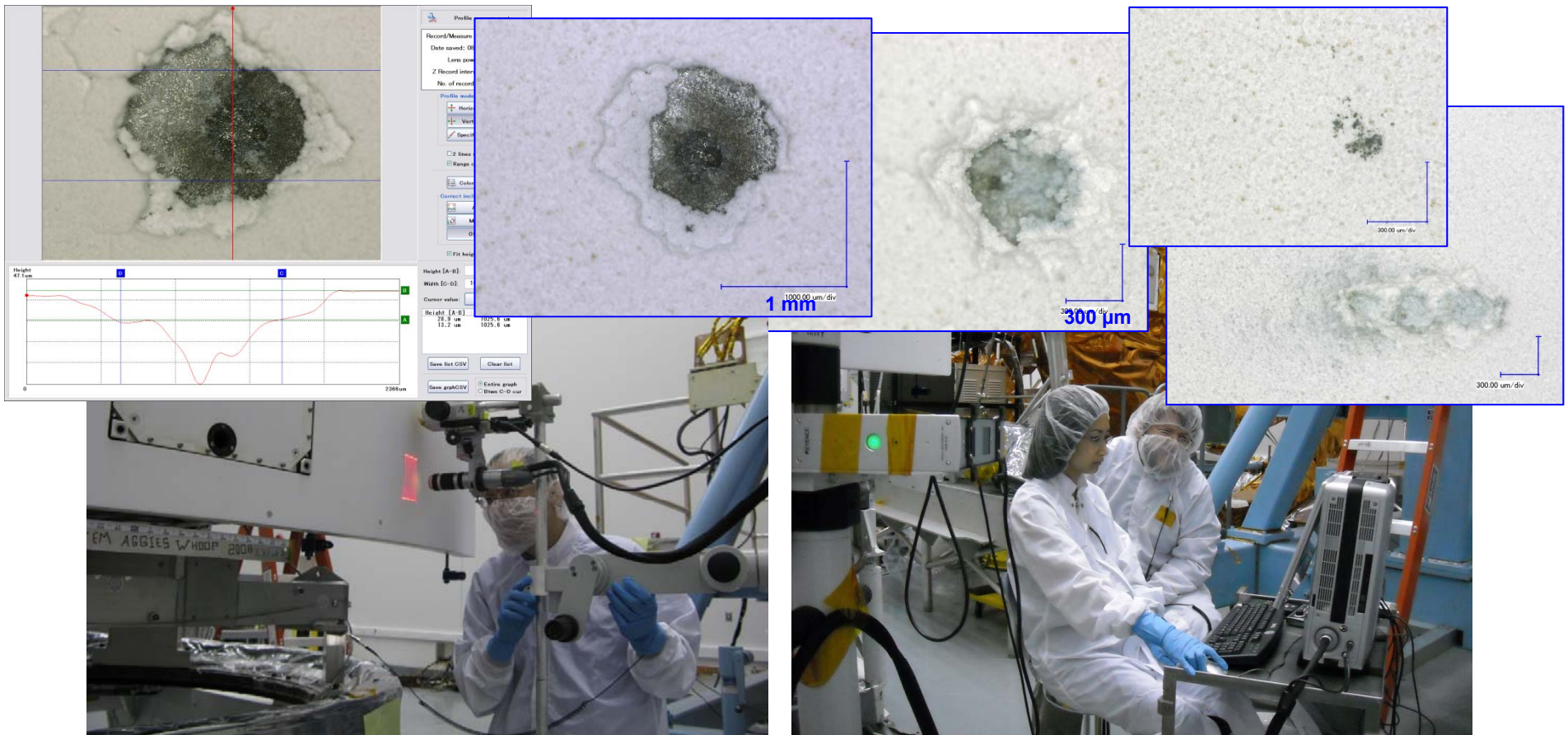
In-Situ Data from Returned Surfaces

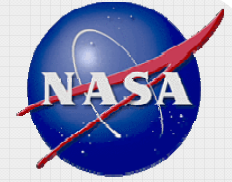




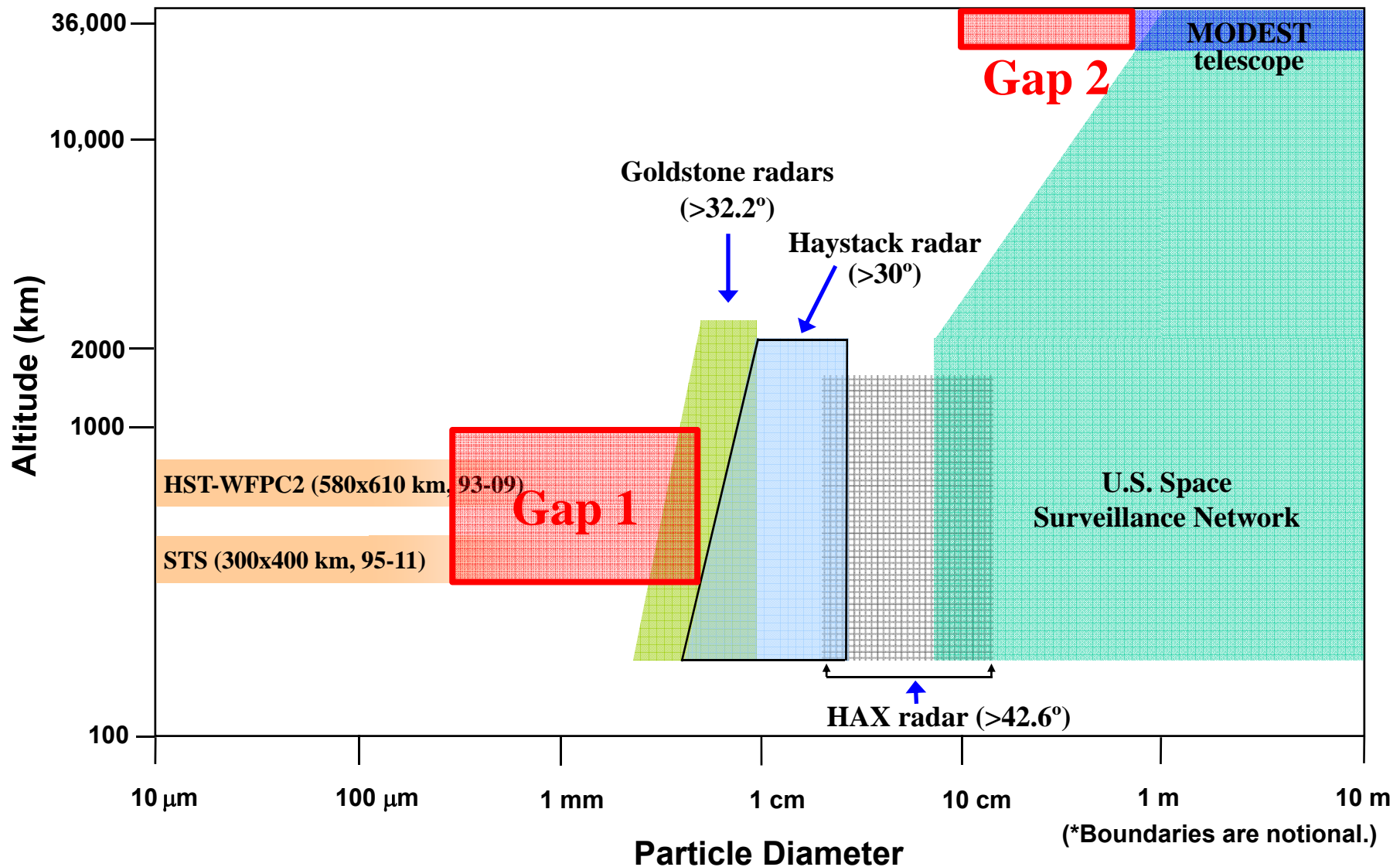
Inspection of the HST WFPC2 Radiator

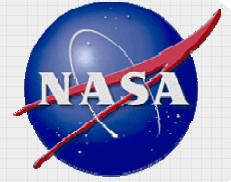
- **685 impact features ($\geq 300 \mu\text{m}$) were identified**
 - Recorded each impact feature's shape, size, depth, and volume






Critical Data Gaps

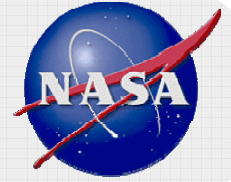




Future NASA Debris Telescope

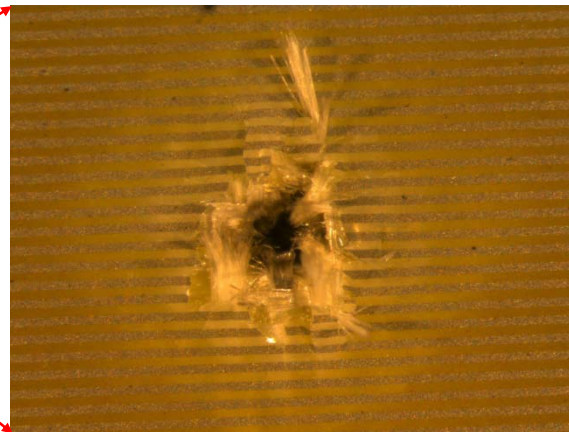
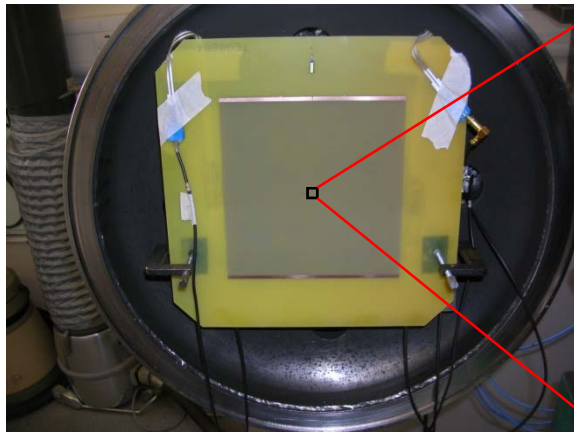
- **NASA Meter Class Autonomous Telescope (MCAT)**
 - 1.3 m aperture, 0.96° field of view, f/4
 - Located at Kwajalein Atoll (9°N , 168°E)
 - Target detection limits
 - **GEO ~10 cm diameter (20.5 V-mag)**
 - Primary objectives
 - **GEO debris down to ~10 cm**
 - **LEO debris with low inclinations and high eccentricities**
 - **Simultaneous radar-optical observations**
 - Expected operations ~2012
- 





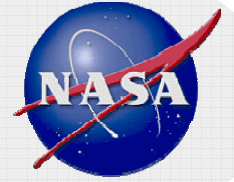
A New Particle Impact Detection Technology

- **Debris Resistive/Acoustic Grid Orbital Navy Sensor (DRAGONS)**
 - Objective: A low-cost/mass/power experiment to detect and characterize 0.1 to 1 mm MMOD particles at 800-1000 km altitude
 - Components: (1) a large surface ($\geq 1 \text{ m}^2$) coated with thin resistive grids, (2) acoustic sensors attached to the backside of the board/film
 - Team: USNA, NASA/ODPO, Kent (UK), NRL, VT
 - Status: Presented to the annual DoD Space Experiment Review Board (SERB) since 2007, no firm flight opportunity identified by STP

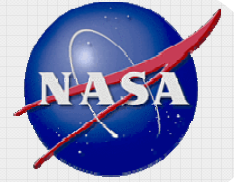


Hypervelocity Impact Tests

- Resistive grid width: $75 \text{ } \mu\text{m}$
- Projectile: 0.3 mm stainless steel
- Impact speed: 5.06 km/sec
- Impact angle: normal
- Two PVDF acoustic sensors attached to the board

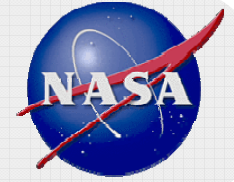


Modeling



General Orbital Debris Modeling (1/2)

- **Evolutionary model**
 - Is a physical model (such as LEGEND) capable of predicting future debris environment
 - Supports the development of US/NASA debris mitigation guidelines and safety standards
- **Engineering model**
 - Is a mathematical model (such as ORDEM) capable of predicting OD impact risks for the International Space Station and other critical space assets
- **Satellite breakup model**
 - Describes the outcome of a satellite breakup (explosion or collision)



General Orbital Debris Modeling (2/2)

- **Reentry risk assessments**
 - Uses Object Reentry Survival Analysis Tool (ORSAT) to evaluate satellite reentry risks
 - The risk of human casualty from surviving debris shall not exceed 1 in 10,000 (NASA Standard 8719.14)



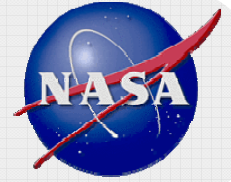
Delta II propellant tank
(Georgetown, TX, 1997)



Titanium casting of STAR-48B SRM
(Saudi Arabia, 2001)

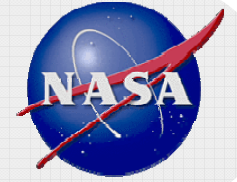


Titanium casting of STAR-48B SRM
(Argentina, 2004)



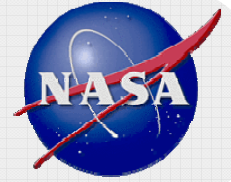
LEGEND

- **LEGEND, A LEO-to-GEO Environment Debris model**
 - Is a high fidelity, three-dimensional numerical simulation model for long-term orbital debris evolutionary studies
 - Includes intact (rocket bodies and spacecraft), mission-related debris (rings, caps, *etc*), and explosion/collision fragments
 - Uses a deterministic approach to mimic the historical debris environment based on recorded launches and breakups
 - Uses a Monte Carlo approach and an innovative, pair-wise collision probability evaluation algorithm to simulate future collision activities
 - Projects future environment based on user-specified launch traffics, postmission disposal and active debris removal options
 - Nine peer-reviewed journal papers have been published about LEGEND and its applications since 2004



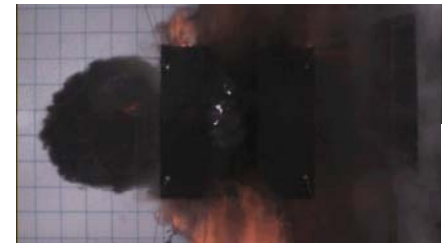
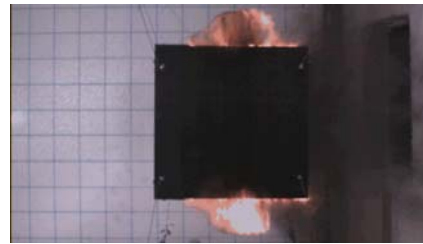
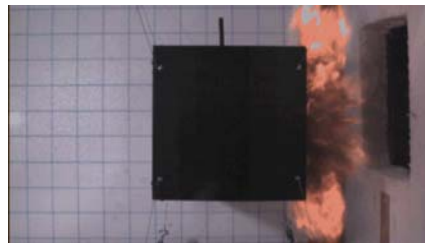
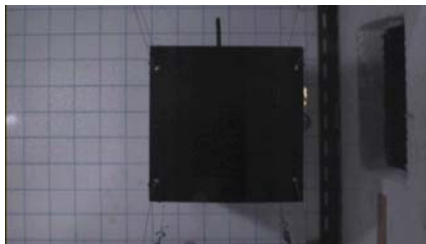
ORDEM

- **ORDEM, An Orbital Debris Engineering Model**
 - Is a mathematical model for orbital debris impact risk assessments for the International Space Station and other critical space assets
 - Describes the orbital debris environment in terms of spatial density, impact velocity distribution, impact flux, etc
 - Is based on recent empirical radar, optical, and in-situ measurement data
 - The current model, ORDEM2000, is available for download at <http://www.orbitaldebris.jsc.nasa.gov/model/engrmodel.html>
 - An updated version, ORDEM 3.0, will be released in the coming months
 - **Extends the coverage to GEO**
 - **Includes uncertainty estimates**

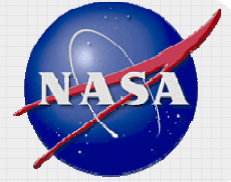


Satellite Breakup Model

- **The NASA Standard Breakup Model**
 - Describes the outcome of a typical satellite explosion or collision
 - **Size, area-to-mass ratio, and ΔV distributions of the fragments**
 - Is a key element for short- and long-term debris modeling
 - Is based on observations of on-orbit breakup events and laboratory experiments
 - Has been adopted by major international space agencies for their debris evolutionary models
 - A new ground-based satellite impact experiment is underway

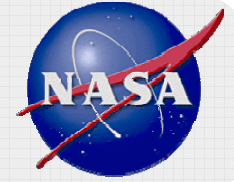


DAS



- **DAS, the NASA Debris Assessment Software**

- Is designed to assist NASA Programs in performing orbital debris assessments for their planned missions
 - **Assessment requirements are described in NASA-STD-8719.14 “Process for Limiting Orbital Debris”**
 - **DAS 2.0 addresses requirements point-by-point**
 - Limit number and orbital lifetime of debris passing through LEO, limit lifetime of objects passing near GEO, limit probability of accidental explosion during mission operations, etc.
- Includes orbit propagators (for LEO, GTO, and GEO), debris environment model, and a simplified version of NASA’s Object Reentry Survival Analysis Tool (ORSAT) for reentry-survivability assessments
- Is available for download at
<http://www.orbitaldebris.jsc.nasa.gov/mitigate/das.html>

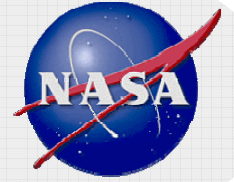


ORSAT

- **ORSAT, NASA's Object Rentry Survival Anal^ysis Tool**
 - Is designed to provide a high fidelity assessment of space vehicle and component reentry survivability
 - **Per U.S. Government Orbital Debris Mitigation Standard Practices, the threshold of human casualty risk from reentering debris shall not exceed 1 in 10,000 per reentry event**
 - Includes trajectory, atmosphere, aerodynamics, aerothermodynamics, thermal / ablation, and debris casualty area analyses
 - Outputs component demise altitude or location, surviving mass, kinetic energy of impact, and human casualty risk



Questions for Part I?

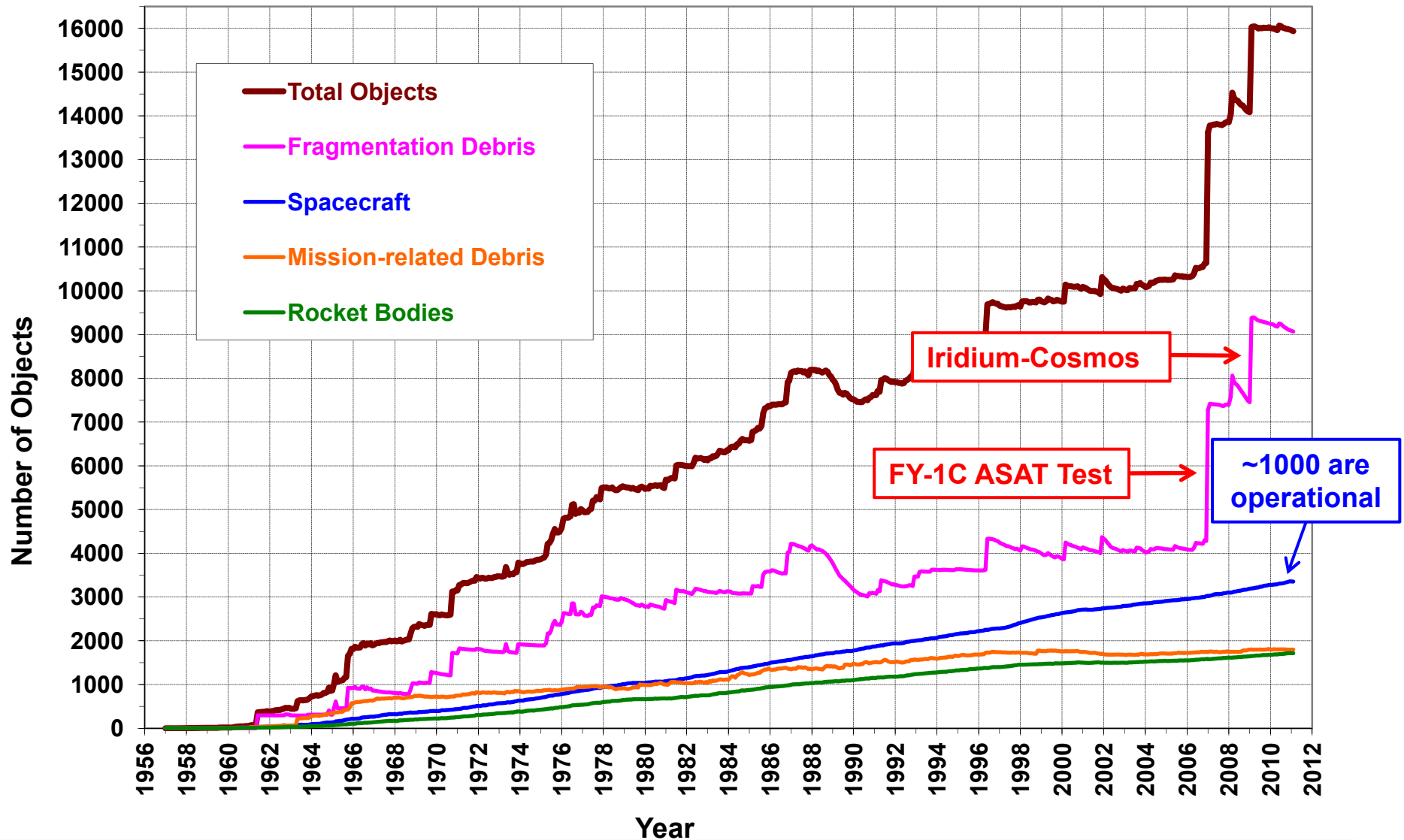


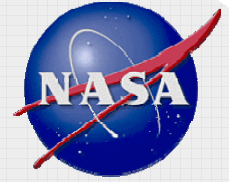
Part 2: Near-Earth Environment Remediation and Active Debris Removal



Growth of the Historical Catalog Populations

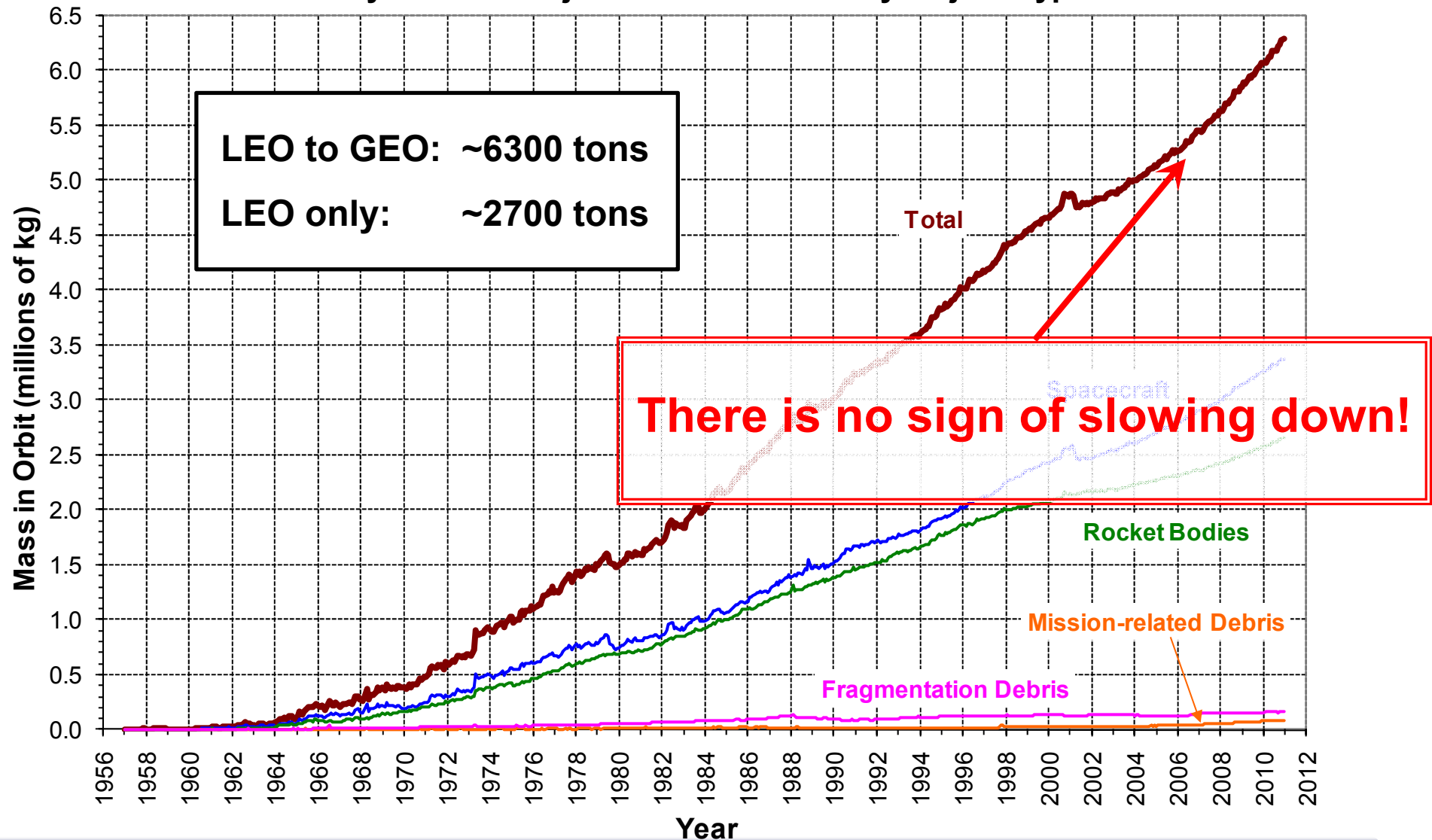
Monthly Number of Objects in Earth Orbit by Object Type (SSN Catalog)

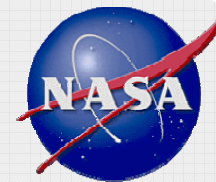




Mass in Orbit

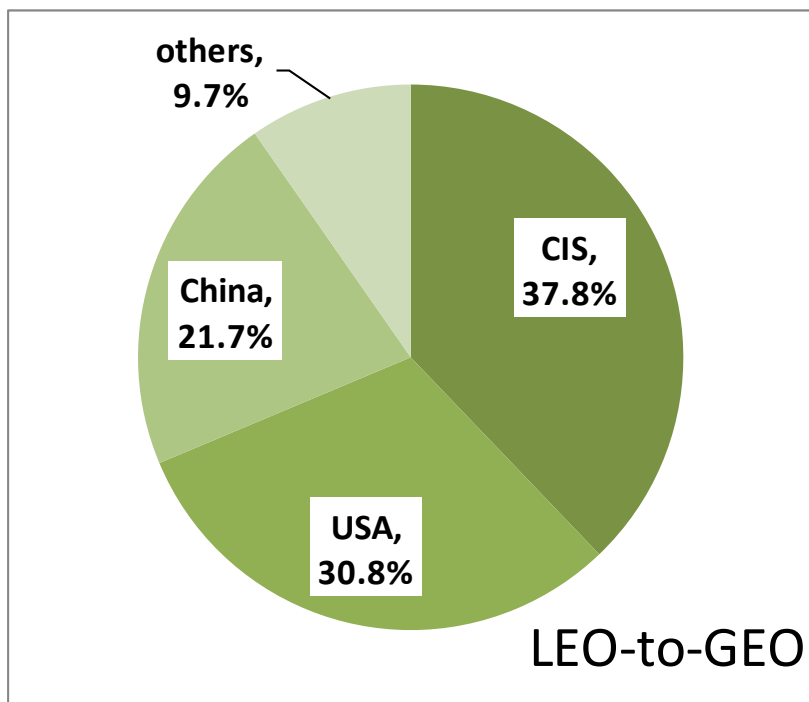
Monthly Mass of Objects in Earth Orbit by Object Type



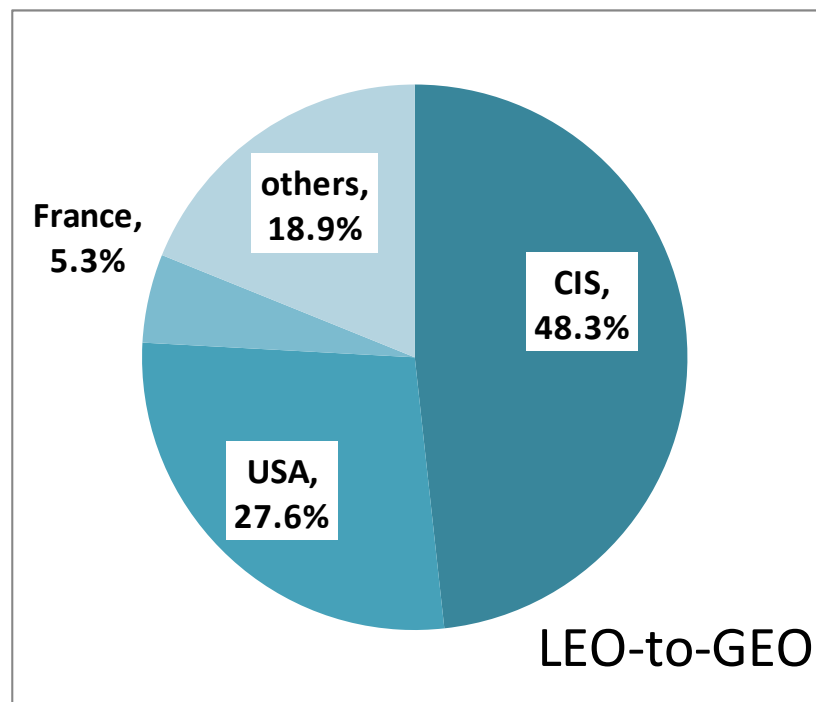


Sources of the Catalog Population – All

Number Breakdown

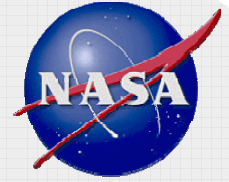


Mass Breakdown

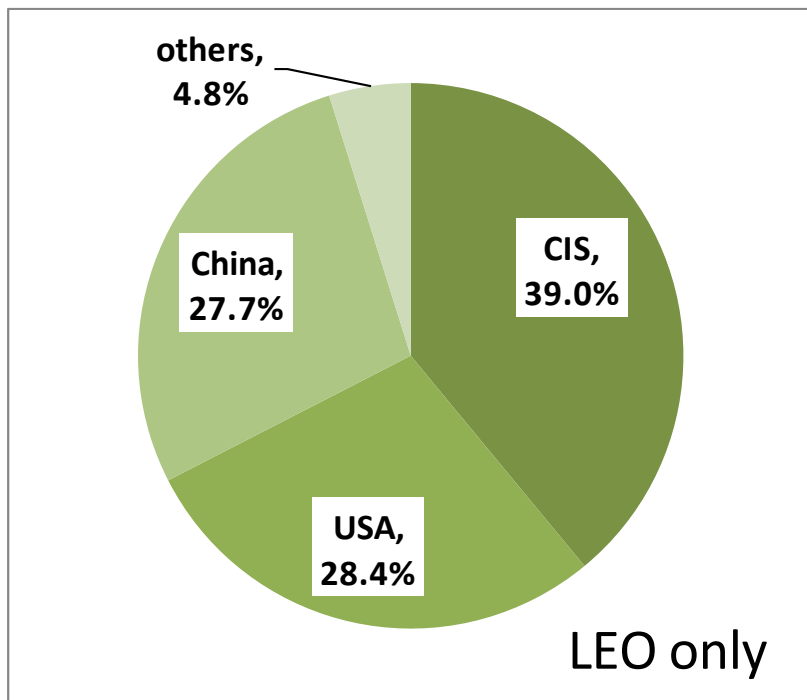


CIS = Former Soviet Republics

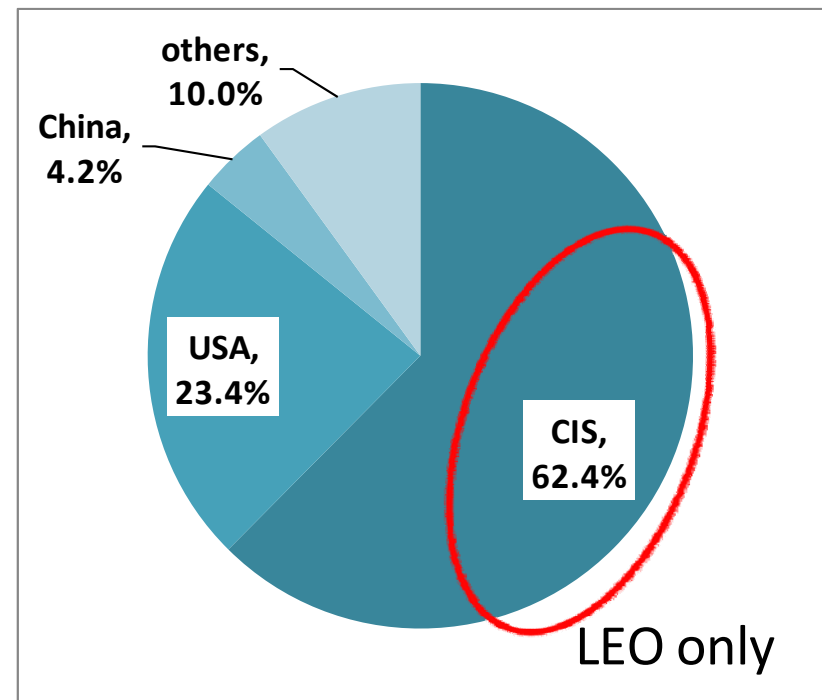
Sources of the Catalog Population – LEO Only



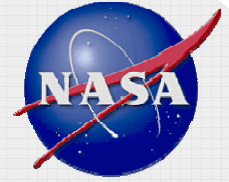
Number Breakdown



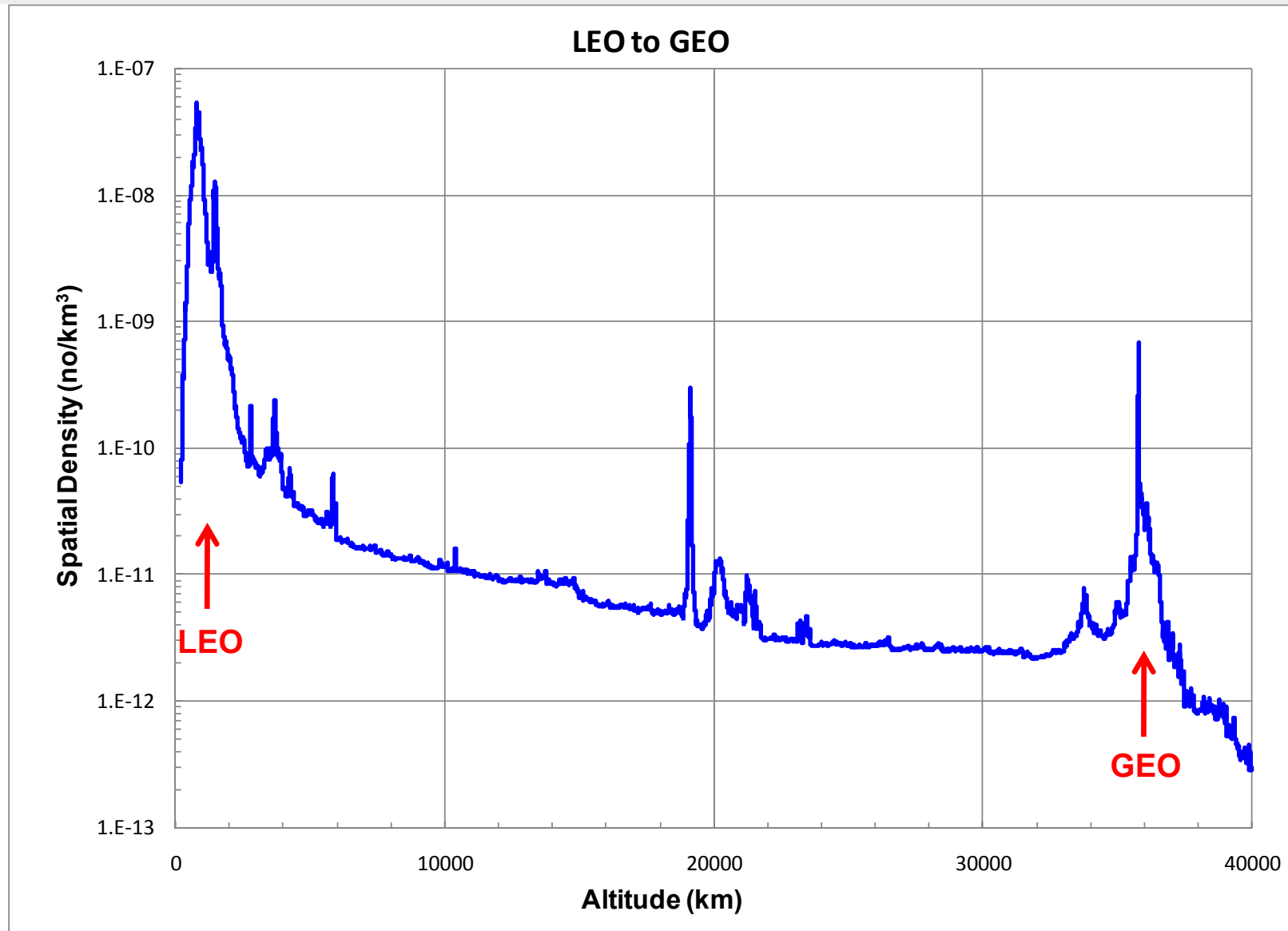
Mass Breakdown

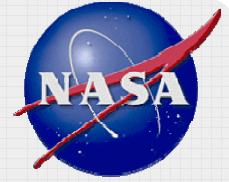


CIS = Former Soviet Republics

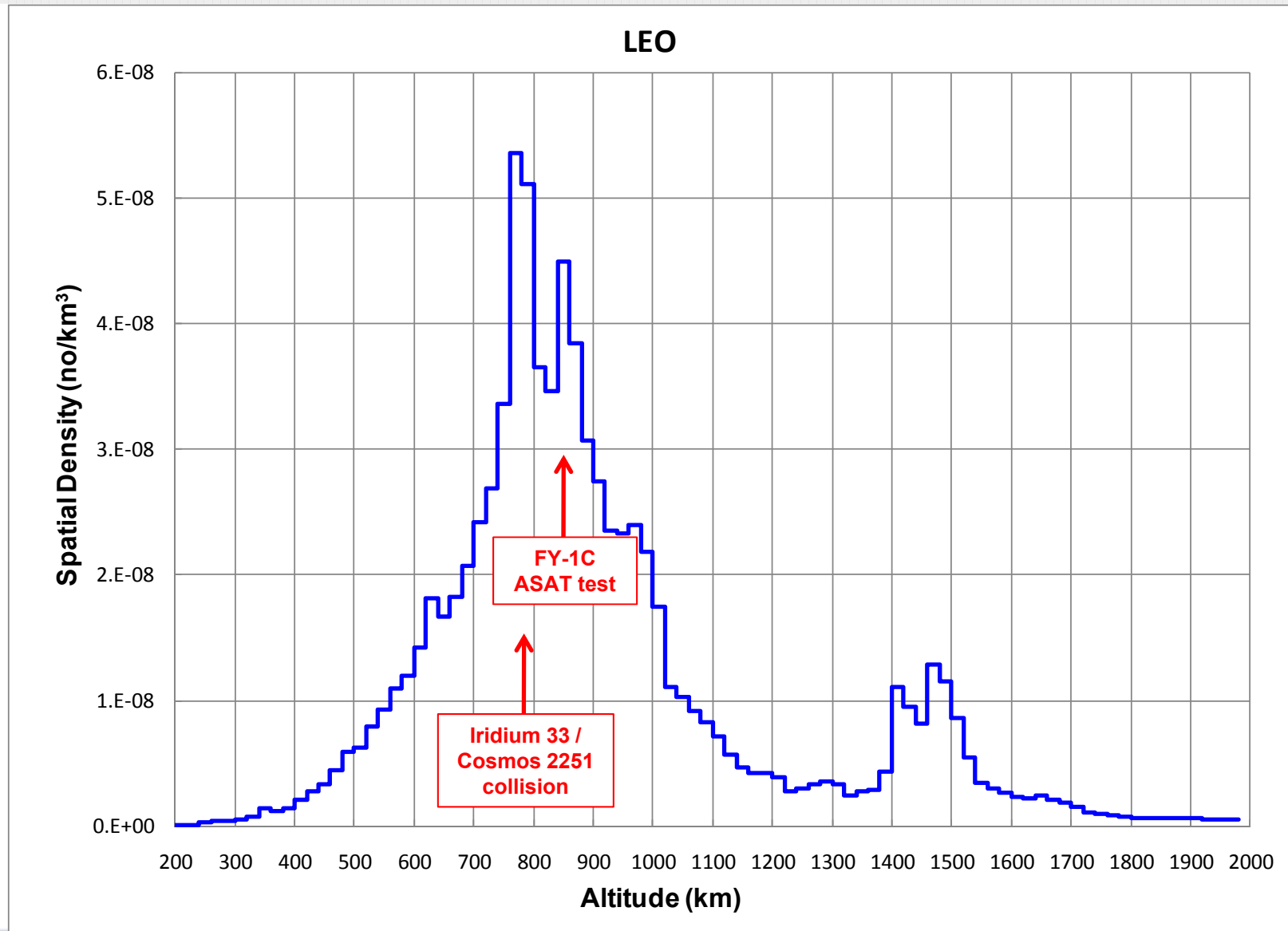


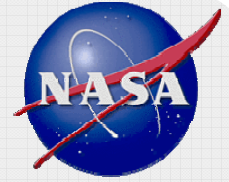
Spatial Density of the Catalog Population (1/2)



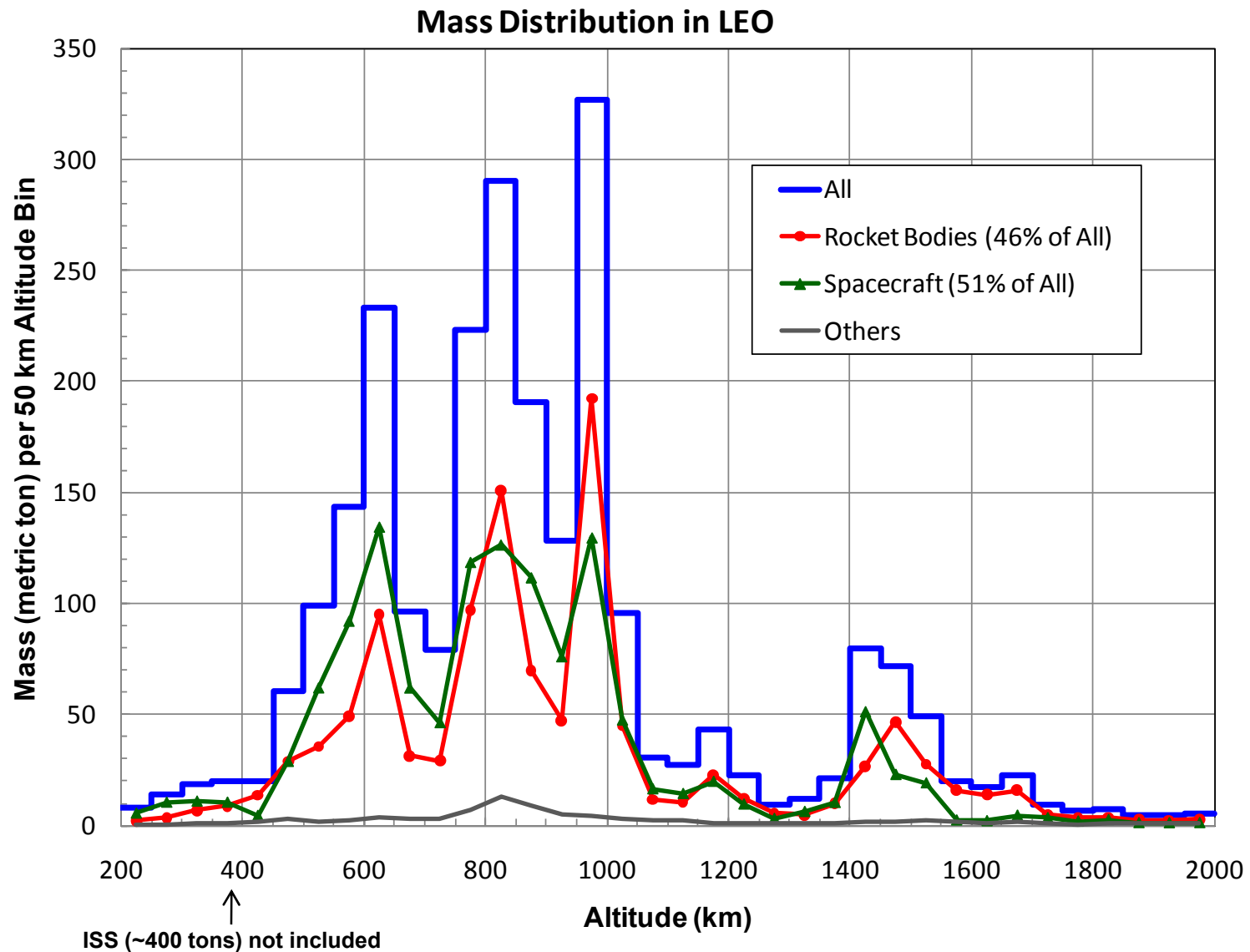


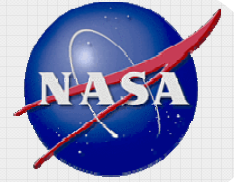
Spatial Density of the Catalog Population (2/2)





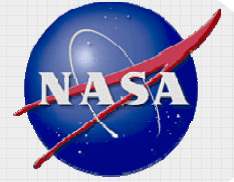
Mass Distribution in LEO





Projected Growth of the Future Debris Environment

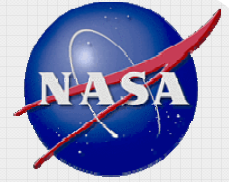
(Worst case, best case, and “realistic” scenarios)



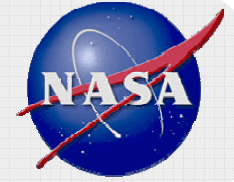
Debris Environment Modeling

- **All environment simulations are based on LEGEND (an LEO-to-GEO Environment Debris model)**
 - LEGEND is the high fidelity orbital debris evolutionary model developed by the NASA Orbital Debris Program Office
 - LEGEND simulates objects individually, incorporates major perturbations in orbit propagation, and includes major source and sink mechanisms (launches, breakups, decays)
 - Ten peer-reviewed journal papers have been published on LEGEND and its applications since 2004
 - The following discussions will focus on ≥ 10 cm objects and limit the future projection to 200 years

Peer-Reviewed Journal Publications (LEGEND and LEGEND Applications)

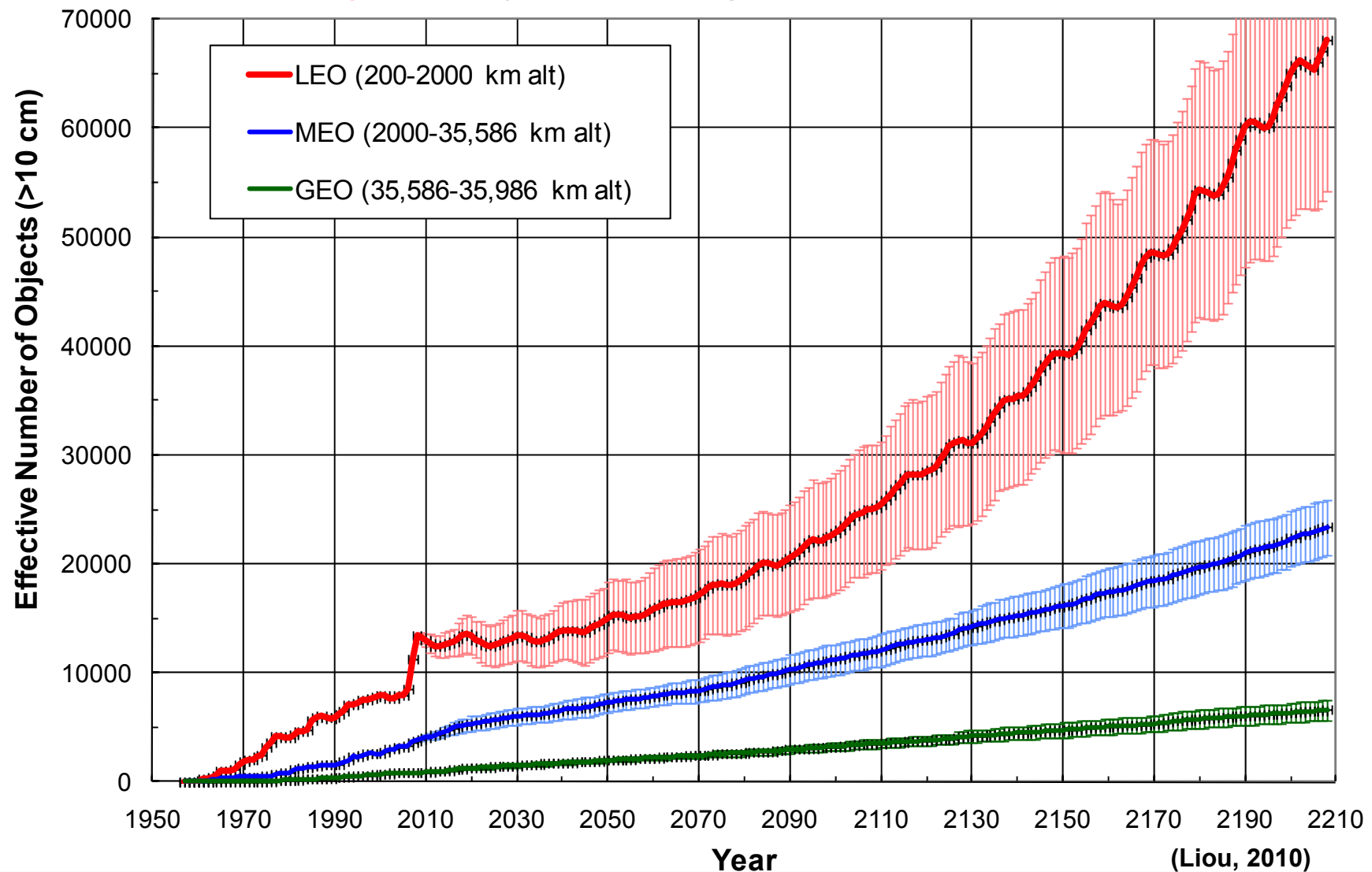


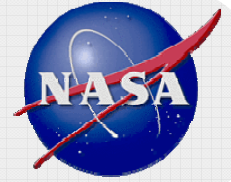
1. Liou, J.-C. *et al.*, LEGEND – A three-dimensional LEO-to-GEO debris evolutionary model. *Adv. Space Res.* 34, 5, 981-986, 2004.
2. Liou, J.-C. and Johnson, N.L., A LEO satellite postmission disposal study using LEGEND, *Acta Astronautica* 57, 324-329, 2005.
3. Liou, J.-C., Collision activities in the future orbital debris environment, *Adv. Space Res.* 38, 9, 2102-2106, 2006.
4. Liou, J.-C. and Johnson, N.L., Risks in space from orbiting debris, *Science* 311, 340-341, 2006.
5. Liou, J.-C., A statistic analysis of the future debris environment, *Acta Astronautica* 62, 264-271, 2008.
6. Liou, J.-C. and Johnson, N.L., Instability of the present LEO satellite population, *Adv. Space Res.* 41, 1046-1053, 2008.
7. Liou, J.-C. and Johnson, N.L., Characterization of the cataloged Fengyun-1C fragments and their long-term effect on the LEO environment, *Adv. Space Res.* 43, 1407-1415, 2009.
8. Liou, J.-C. and Johnson, N.L., A sensitivity study of the effectiveness of active debris removal in LEO, *Acta Astronautica* 64, 236-243, 2009.
9. Liou, J.-C. *et al.*, Controlling the growth of future LEO debris populations with active debris removal, *Acta Astronautica* 66, 648-653, 2010.
10. Liou, J.-C., An active debris removal parametric study for LEO environment remediation, *Adv. Space Res.* 47, 1865-1876, 2011.



Future Projection – The **Worst Case Scenario** (Regular Satellite Launches, but No Mitigation Measures)

Non-Mitigation Projection (averages and 1- σ from 100 MC runs)





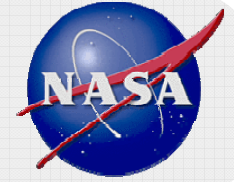
Assessments of the Non-Mitigation Projection

- **LEO: the non-mitigation scenario predicts the debris population (≥ 10 cm objects) will have a rapid non-linear increase in the next 200 years**
 - This is a well-known trend (the “Kessler Syndrome”) that was the motivation for developing the currently-adopted mitigation measures (e.g., the 25-yr rule) in the last 15 years
- **MEO and GEO: the non-mitigation scenario predicts a moderate population growth**
 - Only a few accidental collisions between ≥ 10 cm objects are predicted in the next 200 years
 - The currently-adopted mitigation measures (including EOL maneuvers in GEO) will further limit the population growth
 - Environment remediation is not urgent in MEO and GEO

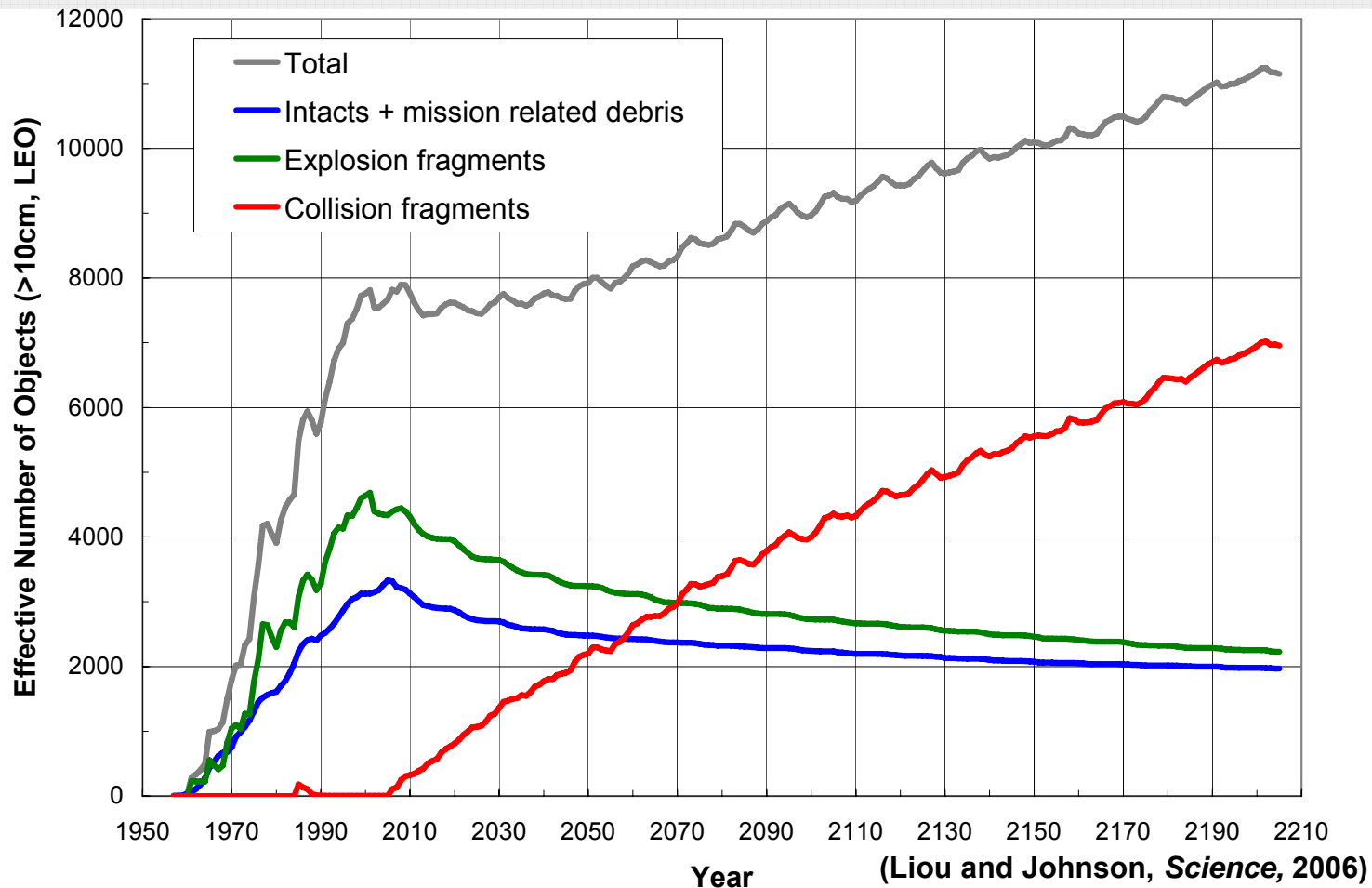


Will the Commonly-Adopted Mitigation* Measures Stabilize the Future LEO Environment?

***Mitigation = Limit the generation of new/long-lived debris (NPR 8715.6A, NASA-STD-8719.14, USG OD Mitigation Standard Practices, UN Debris Mitigation Guidelines, *etc.*)**



Future Projection – The **Best Case Scenario** (**No New Launches** Beyond 1/1/2006)

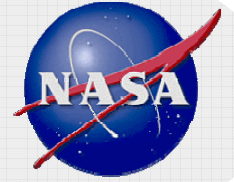


- Collision fragments replace other decaying debris through the next 50 years, keeping the total population approximately constant
- Beyond 2055, the rate of decaying debris decreases, leading to a net increase in the overall satellite population due to collisions



Assessments of the No-New-Launches Scenario

- **In reality, the situation will be worse than the “no new launches” scenario as**
 - Satellites launches will continue
 - Major unexpected breakups may continue to occur (e.g., Fengyun-1C)
- **Postmission disposal (such as a 25-year decay rule) will help, but will be insufficient to prevent the self-generating phenomenon from happening**
- **To preserve the near-Earth space for future generations, ADR must be considered**



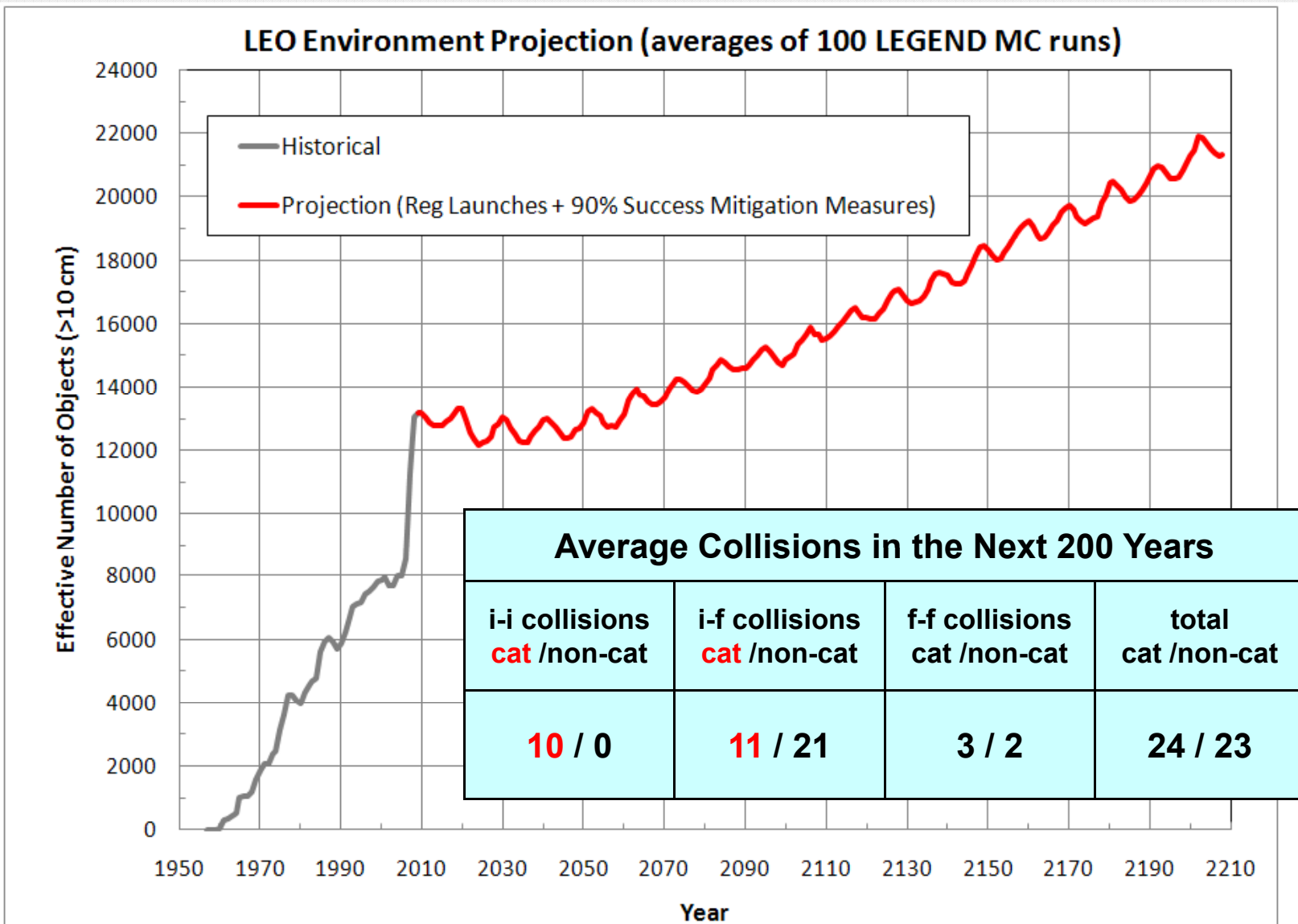
Conclusions of the 2006 Paper

- “The current debris population in the LEO region has reached the point where the environment is unstable and collisions will become the most dominant debris-generating mechanism in the future.”
- “Only remediation of the near-Earth environment – the **removal of existing large objects from orbit** – can prevent future problems for research in and commercialization of space.”

- Liou and Johnson, **Science**, 20 January 2006



Environment Projection With Mitigation Measures





International Consensus

- **The LEO environment instability issue is under investigation by the Inter-Agency Space Debris Coordination Committee (IADC) members**
- **An official “Stability of the Future LEO Environment” comparison study, was initiated in 2009**
 - Six participating members: NASA (lead), ASI, ESA, ISRO, JAXA, and UKSA
 - Results from the six different models are consistent with one another, *i.e.*, **even with a good implementation of the commonly-adopted mitigation measures, the LEO debris population is expected to increase in the next 200 years**
 - Study summary was presented at the April 2011 IADC meeting





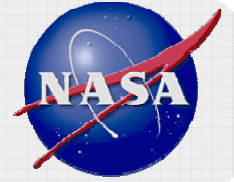
Preserving the Environment with Active Debris Removal (ADR*)

***ADR = Removing debris beyond guidelines of current mitigation measures**



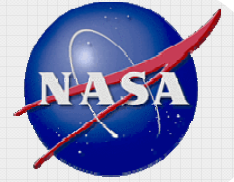
Key Questions for ADR

- **Where is the most critical region for ADR?**
 - **What are the mission objectives?**
 - **What objects should be removed first?**
 - The debris environment is very **dynamic**. Breakups of large intacts generate small debris, small debris decay over time,...
 - **What are the benefits to the environment?**
 - **How to do it?**
- **The answers will drive the top-level requirements, the necessary technology development, and the implementation of ADR operations**

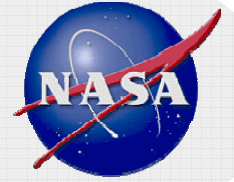


How to Define Mission Success?

- **Mission objectives guide the removal target selection criteria and the execution of ADR**
 - **Common objectives**
 - Follow practical/mission constraints (in altitude, inclination, class, size, *etc.*)
 - Maximize benefit-to-cost ratio
 - **Specific objectives**
 - Control population growth (small & large debris)
 - Limit collision activities
 - Mitigate mission-ending risks (not necessarily catastrophic destruction) to operational payloads
 - Mitigate risks to human space activities
 - And so on
- Target large & massive intacts
- Target small debris

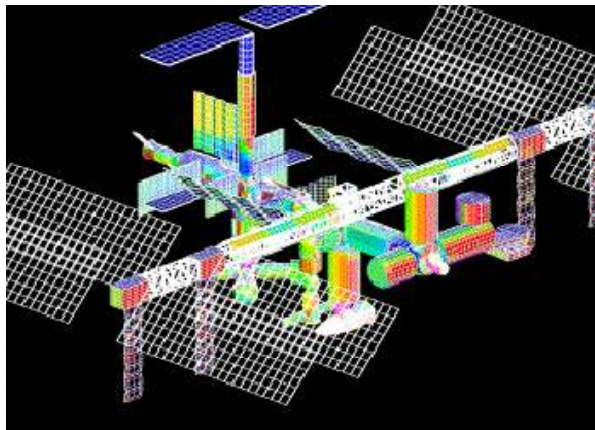


Target Small Debris

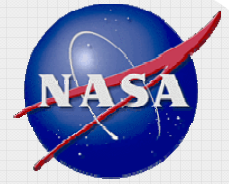


One Example: Risks From Small Debris

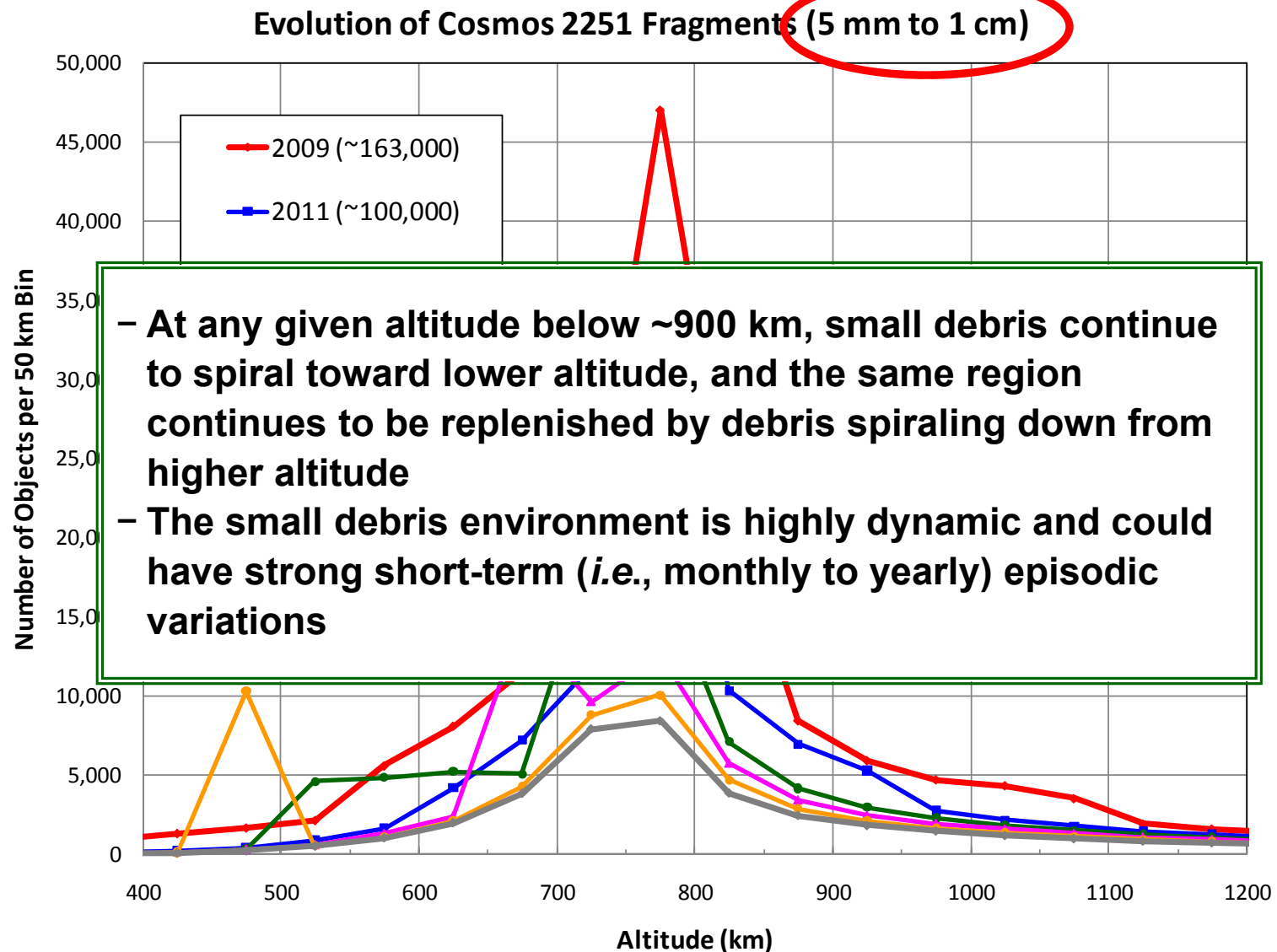
- **The U.S. segments of the ISS are protected against orbital debris about 1.4 cm and smaller**
 - “Currently,” the number of objects between 1.5 cm and 10 cm, with orbits crossing that of the ISS, is approximately 1200
 - ~800 of them are between 1.5 cm and 3 cm
 - To reduce 50% of the ISS-crossing orbital debris in this size range (1.5 cm to 3 cm) will require, for example, a debris collector/remover with an area-time product of $\sim 1000 \text{ km}^2 \text{ year}$

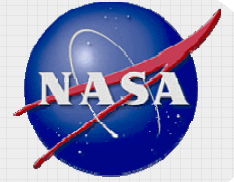


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Small Debris Environment Is Highly Dynamic





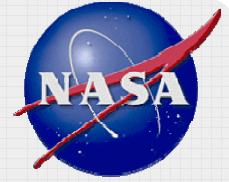
Target Large Debris



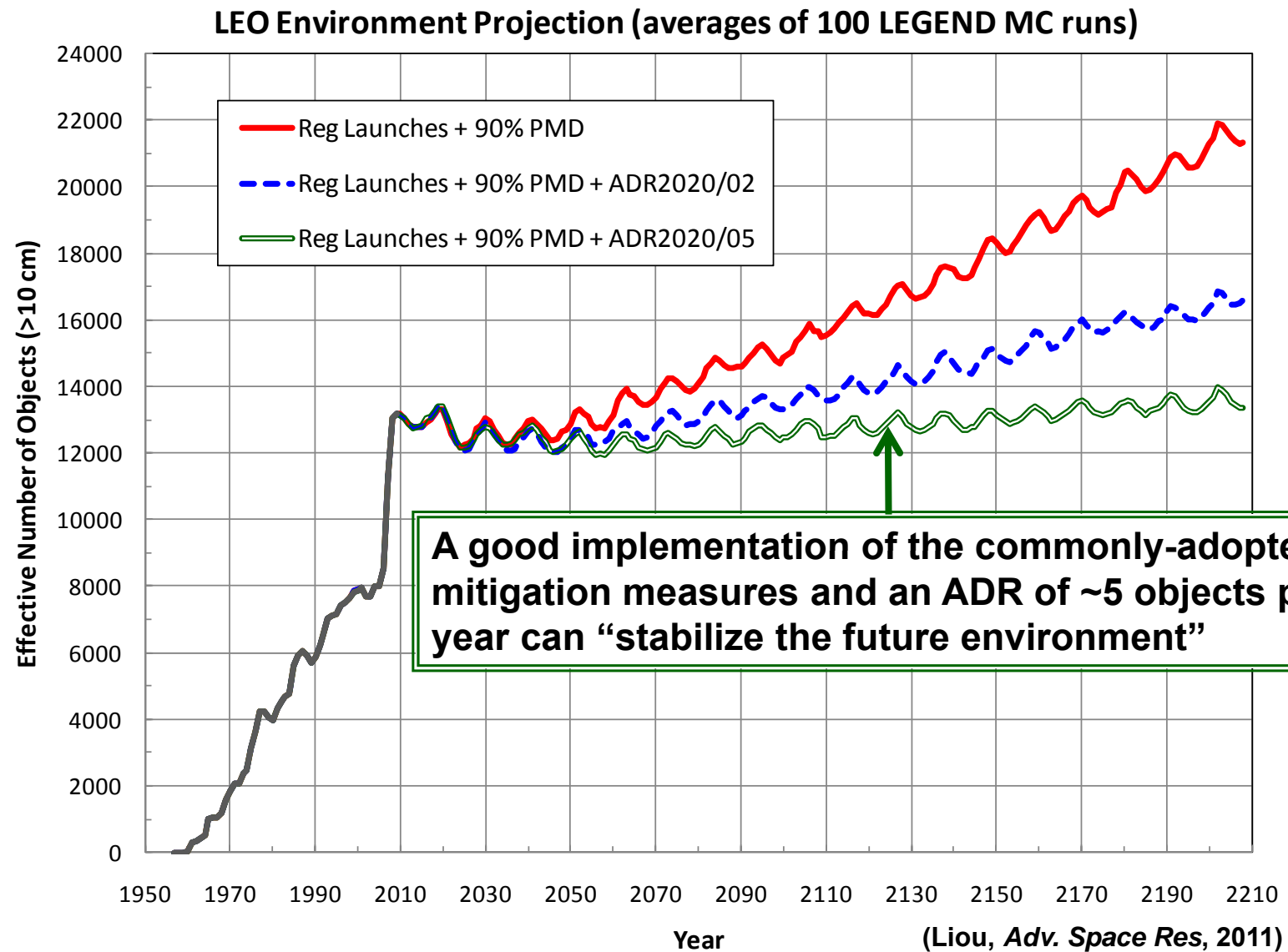
Targeting the Root Cause of the Problem

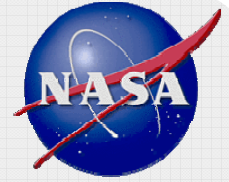
- **A 2008-2009 NASA study shows that the two key elements to stabilize the future LEO environment (in the next 200 years) are**
 - A good implementation of the commonly-adopted mitigation measures (passivation, 25-year rule, avoid intentional destruction, *etc.*)

- An active debris removal of about five objects per year
 - These are objects with the highest [$M \times P_{\text{coll}}$]
 - Many (but not all) of the potential targets in the current environment are spent Russian SL upper stages
 - **Masses:** 1.4 to 8.9 tons
 - **Dimensions:** 2 to 4 m in diameter, 6 to 12 m in length
 - **Altitudes:** ~600 to ~1000 km regions
 - **Inclinations:** ~7 well-defined bands

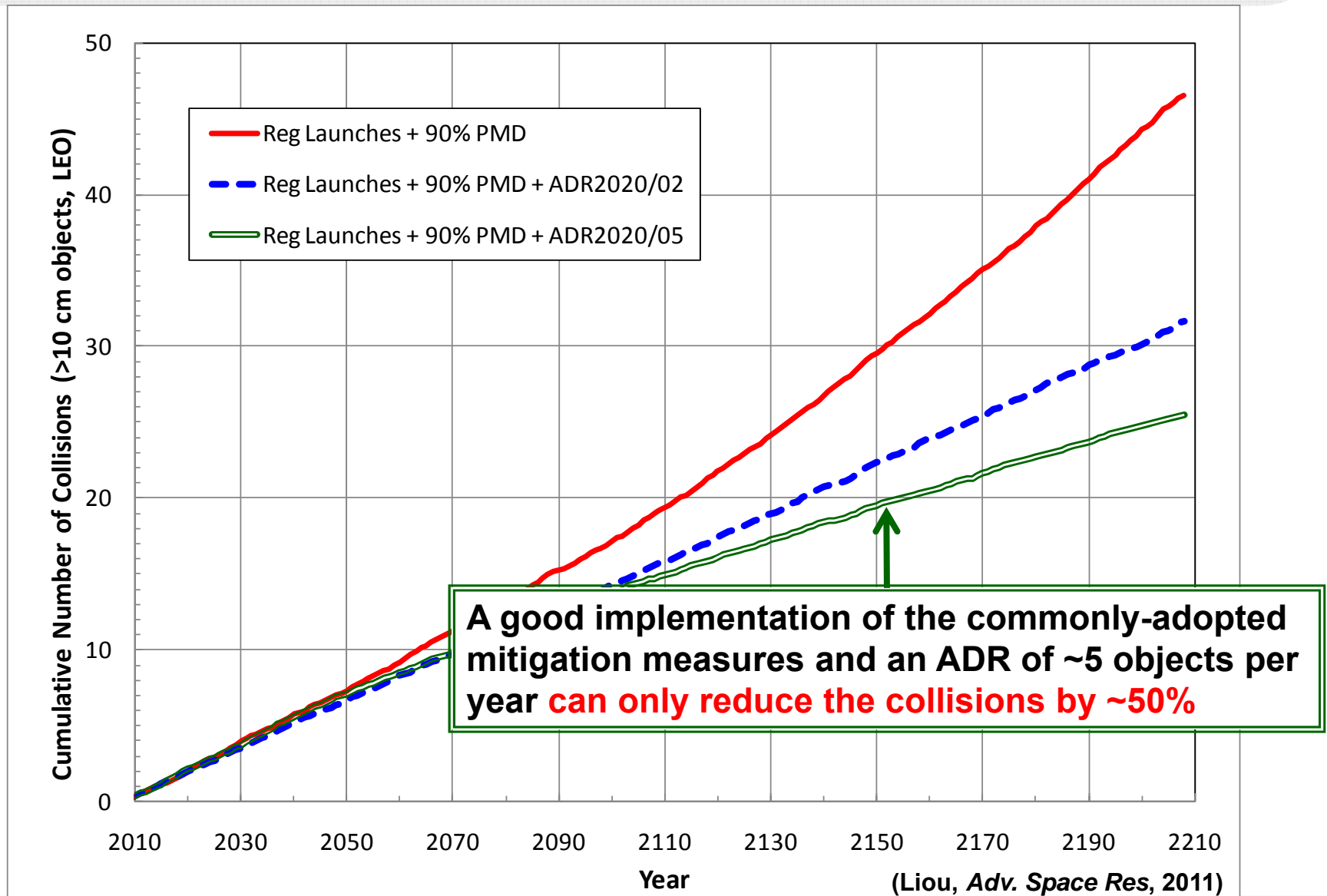


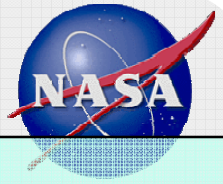
Controlling Debris Growth with ADR





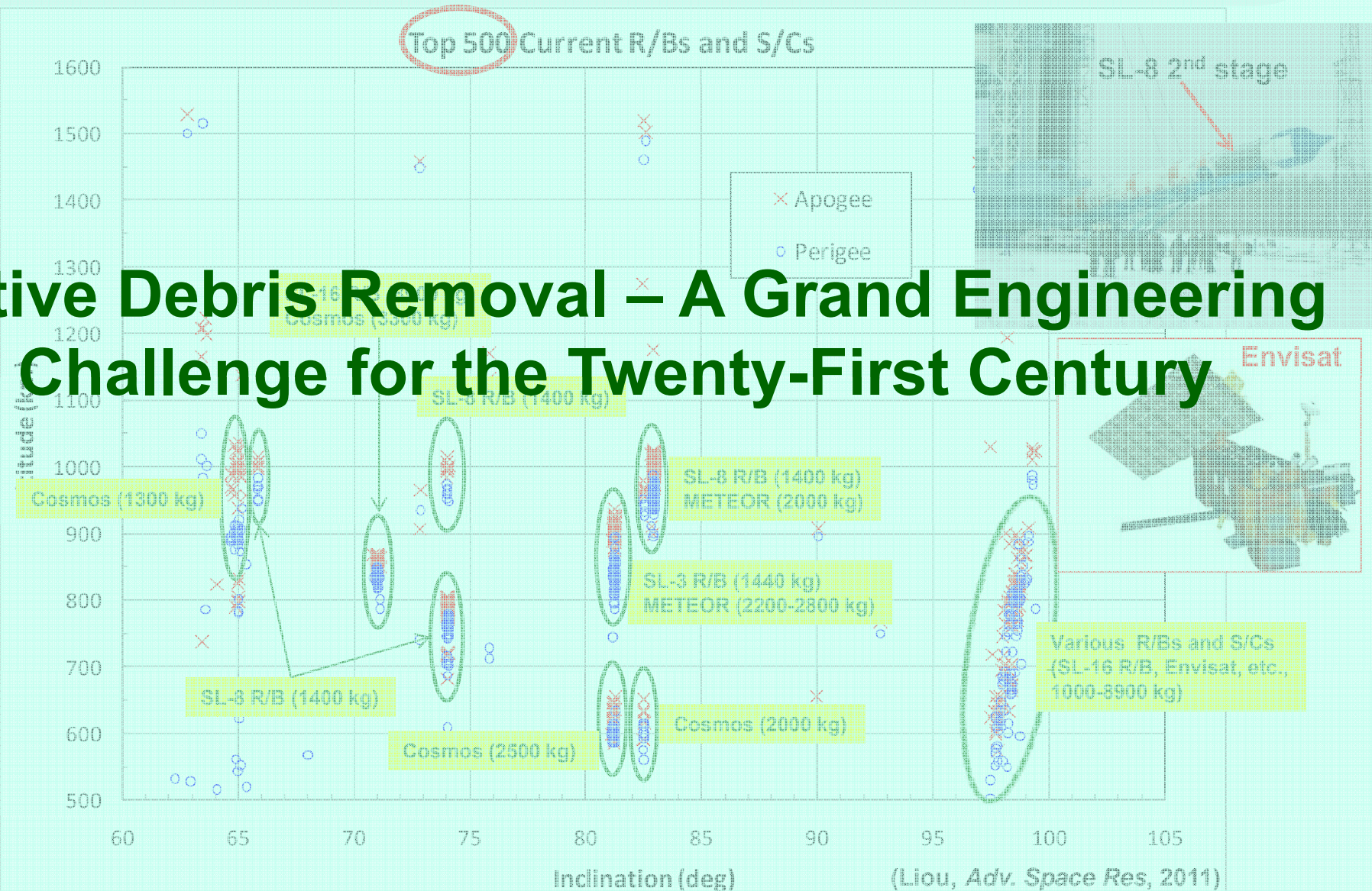
Projected Collision Activities in LEO



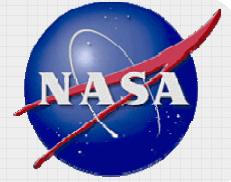


Potential Active Debris Removal Targets

Active Debris Removal – A Grand Engineering Challenge for the Twenty-First Century



National Space Policy of the United States of America (28 June 2010)



- **Orbital debris is mentioned on 4 different pages for a total of 10 times in this 14-page policy document**
- **On page 7:**

Preserving the Space Environment and the Responsible Use of Space

Preserve the Space Environment. For the purposes of minimizing debris and preserving the space environment for the responsible, peaceful, and safe use of all users, the United States shall:

- ...
- **Pursue research and development of technologies and techniques,** through the Administrator of the National Aeronautics and Space Administration (NASA) and the Secretary of Defense, to mitigate and **remove on-orbit debris**, reduce hazards, and increase understanding of the current and future debris environment; and
- ...

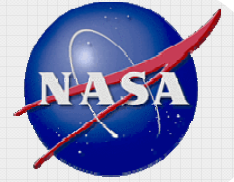


Challenges for ADR Operations

Operations	Technology Challenges
Launch	Single-object removal per launch is not feasible from cost perspective
Propulsion	Solid, liquid, tether, plasma, laser, drag-enhancement devices, others?
Precision Tracking	Ground or space-based
GN&C and Rendezvous	Autonomous, non-cooperative targets
Stabilization (of the tumbling targets)	Physical or non-physical, how
Capture or Attachment	Physical (where, how) or non-physical (how), do no harm
Deorbit or Graveyard Orbit	When, where reentry ground risks

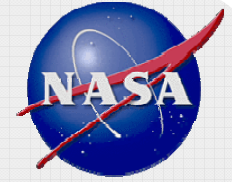
- **Other requirements:**

- Affordable cost
- Repeatability of the removal system (in space)
- Target R/Bs first

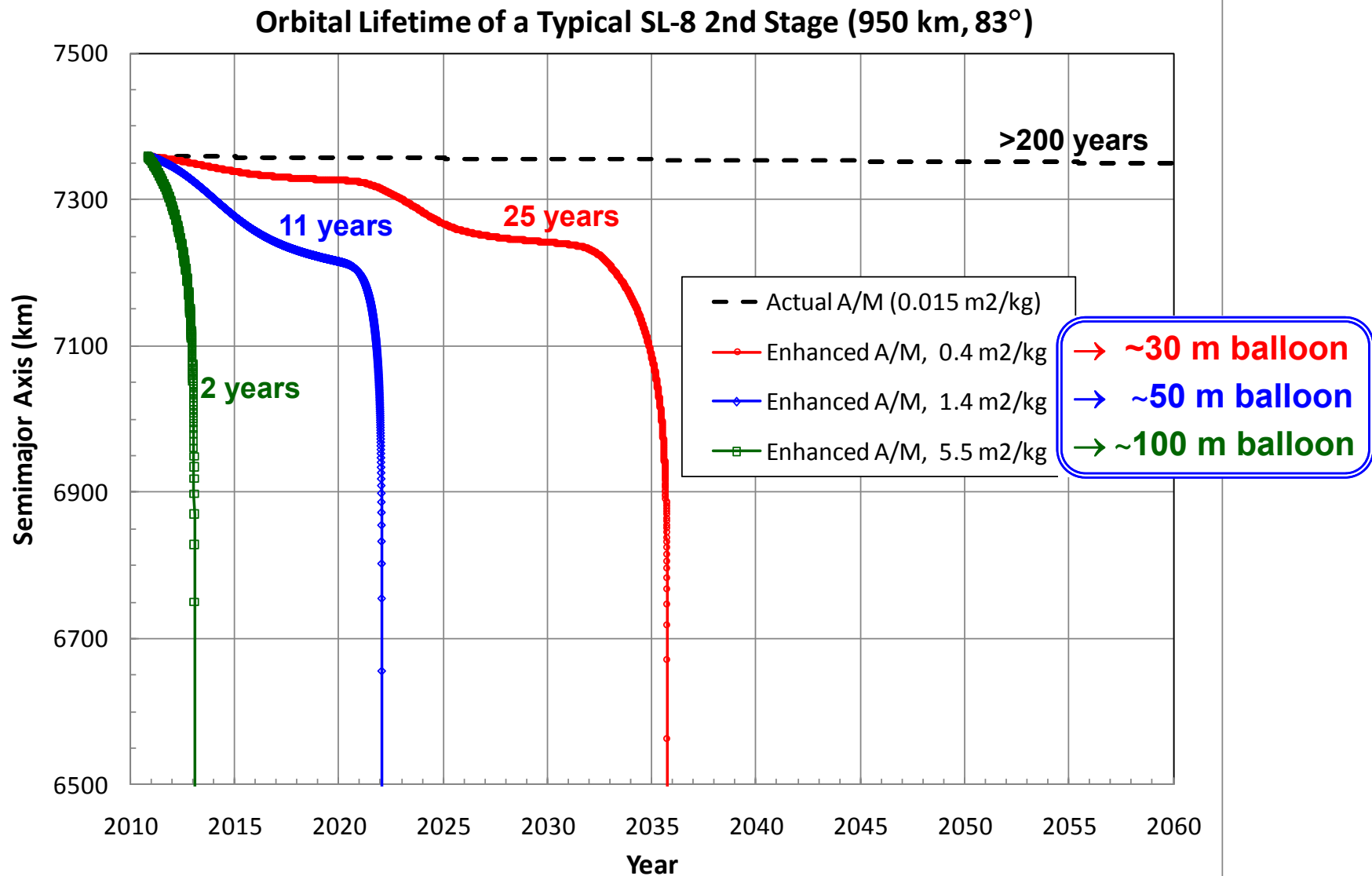


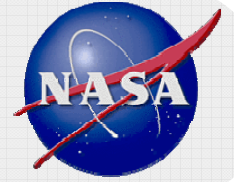
The First Step

- **Identify top-level requirements for an end-to-end ADR operation**
 - Launch, propulsion, precision tracking, GN&C, rendezvous, stabilization, capture/attachment, and deorbit/graveyard maneuvers
 - Define stakeholders and their expectations to drive the development of a concept of operations
- **Conduct mission design analyses and establish a feasible forward plan**
 - Identify TRLs of existing technologies
 - Evaluate pros and cons of different technologies (e.g., space tug vs. drag-enhancement devices)
 - Identify technology gaps (e.g., ways to stabilize a massive, non-cooperative, fast spinning/tumbling target)
 - Perform trade studies (e.g., physical vs. non-physical capture; deorbit vs. graveyard orbit)

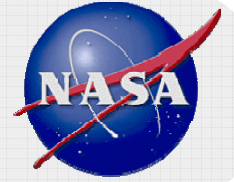


An Example – Deorbit With Drag-Enhancement Devices



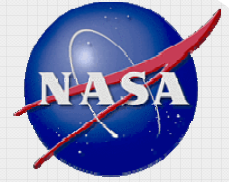


Summary

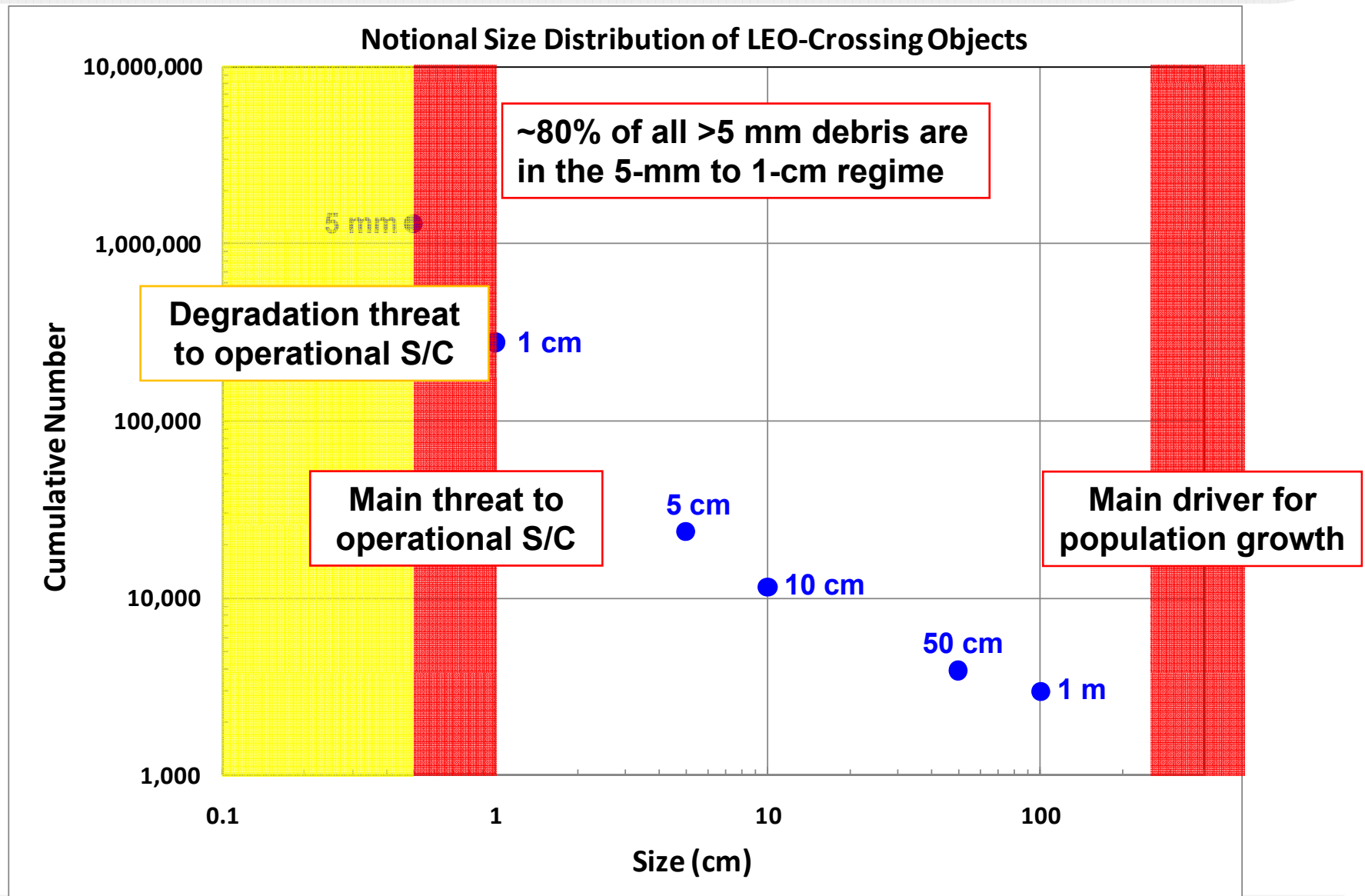


Concluding Remarks (1/4)

- **The LEO debris population will continue to increase even with a good implementation of the commonly-adopted mitigation measures**
 - The increase is driven by catastrophic collisions involving large and massive intacts
 - The major mission-ending risks for most operational satellites, however, comes from impacts with debris just above the threshold of the protection shields (~5 mm to 1 cm)



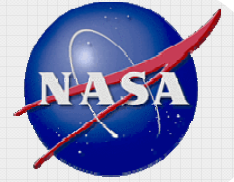
Concluding Remarks (2/4)





Concluding Remarks (3/4)

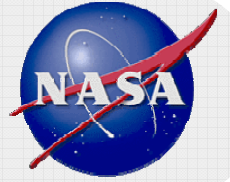
- **To address the root cause of the population growth (for large and small debris)**
 - **Target objects with the highest [$M \times P_{\text{coll}}$]**
 - To maintain the future LEO debris population at a level similar to the current environment requires an ADR of ~5 massive intacts per year
- **To address the main threat to operational satellites**
 - **Target objects in the 5-mm-to-1-cm regime**
 - The small debris environment is highly dynamic and will require a long-term operation to achieve the objective
- **Targeting anything else will NOT be the most effective means to remediate the environment nor to mitigate risks to operational satellites**



Concluding Remarks (4/4)

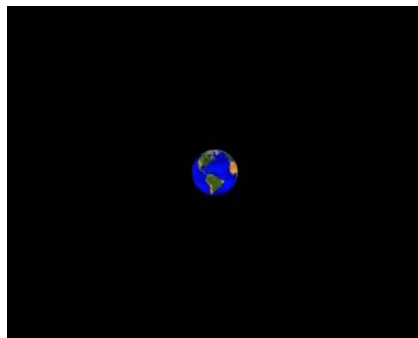
- **There is a need for a top-level, long-term strategic plan for environment remediation**
 - Define “what is acceptable”
 - Define the mission objectives
 - Establish a roadmap/timeframe to move forward
- **The community must commit the necessary resources to support the development of low-cost and viable removal technologies**
 - Encourage dual-use technologies
- **Address non-technical issues, such as policy, coordination, ownership, legal, and liability at the national and international levels**

Preserving the Environment for Future Generations

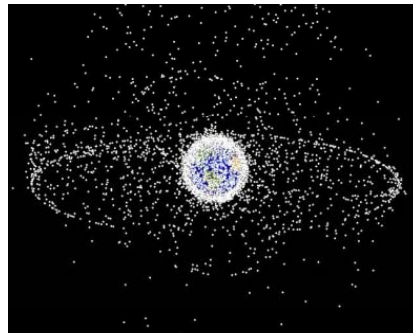


- **Four Essential “Cs” for ADR**

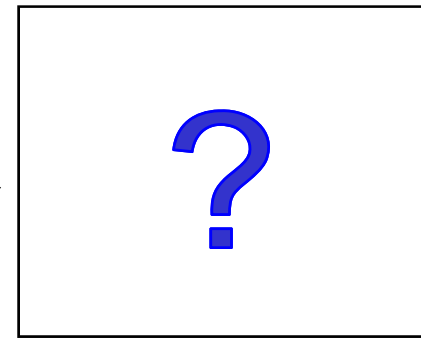
- Consensus
- Cooperation
- Collaboration
- Contributions



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